

LUALUALEI NAVAL ROAD/KUNIA ROAD

CONNECTOR ROAD CONCEPT STUDY

8/27/01



**Gray • Hong • Bills • Nojima & Associates, Inc.**

CONSULTING ENGINEERS



**LUALUALEI NAVAL ROAD/KUNIA ROAD**

**CONNECTOR ROAD CONCEPT STUDY**

Prepared For

Department of Transportation Services  
City and County of Honolulu  
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Honolulu, Hawaii 96813

Prepared By

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August 27, 2001

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# **LUALUALEI NAVAL ROAD/KUNIA ROAD CONNECTOR ROAD CONCEPT STUDY**

## **AUTHORIZATION**

The Lualualei Naval Road/Kunia Road Connector Road Concept Study has been prepared in conjunction with the Waianae Coast Emergency Access Road Plan (WCEAR) developed and prepared by Gray, Hong, Bills, Nojima & Associates, Inc. (GHBN) and authorized by the City and County of Honolulu Department of Transportation Services.

## **INTRODUCTION AND BACKGROUND**

The WCEAR's goal is to develop an integrated and coordinated roadway plan to assist traffic movement along the Leeward Coast when segments of Farrington Highway are impassable. The project includes physical roadway improvements and operational components. The limits of the Plan are confined to existing local streets and new local street connectors as generally described on the City and County of Honolulu Waianae Coast Community Sustainable Plan-Land Use Map.

One of the basic concepts of the WCEAR project is that it be community driven and active community involvement is integral to the designation of the physical roadway improvements which will ultimately be constructed.

During the initial public interaction sessions, it became obvious that there was a noticeable desire to at least recognize that a roadway over/through the Waianae Mountain Range would enhance traffic movement on the Waianae Coast. This statement is particularly valid when there is traffic stoppage on Farrington Highway in the Nanakuli area. Within the Nanakuli area, there are limited options to use existing and/or new local streets to bypass the highway.

While it is recognized that the Navy's Kolekole Pass Road exists, use of this roadway is severely limited due to coordination with the Navy in a timely manner, wind usability restrictions and Navy operations restrictions. Therefore, this route does not fulfill the basic criteria to be considered a reliable element of an emergency access/bypass route.

The State of Hawaii Department of Transportation did a preliminary evaluation of a roadway system over the Waianae Range which included a major roadway improvement in the mauka region of the Leeward Coast connecting to the Waianae Range crossing. However, this study had a projected cost of \$500,000,000 (not including land costs) and the concept was deemed unfeasible.

As a result of the community interest and as a result of the fact that Kolekole Pass is inadequate and the State has no current plans, this Waianae Range roadway crossing study has been conducted.

## **SCOPE OF STUDY**

The scope of this study is to provide a concept feasibility analysis of constructing a connector roadway between Lualualei Naval Road and Kunia Road crossing the Waianae Range at Pohakea Pass. The study has been limited to evaluation of physical construction criteria including alignment (horizontal and vertical) based on available topographic information (aerial topography and U.S.G.S. topography) and soils evaluation based on literature review of existing information and mapping. This evaluation has produced an order of magnitude cost estimate.

The study also identifies the work necessary to advance to a future more refined analysis which would be necessary if the order of magnitude cost projection finds funding. One obvious future work element would be coordination with the Navy and the Estate of James Campbell, the affected landowners.

## **PROPOSED ROADWAY DESCRIPTION**

The proposed roadway alignment is shown on Figure 1. The roadway connects to Kunia Road approximately <sup>3.55</sup>0.4 mile north of the H-1 Freeway Kunia Interchange. The roadway also connects to Lualualei Naval Road outside of the Lualualei Naval Magazine main security gate.

The proposed roadway is intended to primarily provide an alternative emergency access route from the Leeward Coast. However, it is recognized that this roadway

would also be used on a permanent and regular basis by motorists finding it convenient. In keeping with the primary function, a two-lane/two-way roadway has been evaluated. The selected typical roadway section has two 12-foot wide traveling lanes and a 10-foot wide shoulder on each side providing a total 44-foot wide roadway section. The typical roadway section is shown on Figure 2.

A major feature of the roadway system is a 5,200-foot long tunnel system through the crest of Pohakea Pass. Potential typical tunnel system cross-sections are shown on Figure 3. One of the factors influencing the selection/evaluation of a tunnel system was impact on the environment caused by significant grading to broach the top of Pohakea Pass and its resulting impact on archaeological/cultural considerations. Generally, it is intended that the tunnel segment match that of the Pali Highway as compared to an H-3 tunnel section with "interstate" highway standards.

## **TECHNICAL CONSIDERATIONS**

A conceptual design showing the plan and profile of the proposed roadway is shown on Figures 4 through 9. The following items describe basic project development assumptions:

### **Design Speed**

The roadway has been developed with horizontal, vertical and super elevation criteria applicable for a 45 MPH design speed and a 35 MPH posted speed based

on City and County of Honolulu design criteria. This design speed is considered compatible with the roadway's primary purpose.

### Pavement Design

The maximum vertical grade has been limited to less than 12 percent (5 percent in the tunnel). This allows the use of asphaltic concrete pavement. Steeper grades would necessitate the use of concrete. A flatter vertical grade would be appropriate if the connector was to be considered a major Leeward Coast connector. However, in keeping with the roadway's primary purpose, the 12 percent gradient (maximum) has been utilized.

### Soils Analysis

Appendix A provides an analysis of soils anticipated based on the conceptual design alignment. The analysis has been limited to evaluation of soils considerations based on review of existing documentation and has not been field verified by any reconnaissance (borings, etc.).

Soils on the Kunia side of the roadway alignment are anticipated to be available for reuse as part of the roadway prism for cut and fill. For the Lualualei side of the alignment, reuse of material may be limited due to expansive soil conditions and size of material generated.

## Tunnel Analysis

The Concept Study proposes the use of a two-lane, bi-directional tunnel (single traveling lanes operating in opposing directions within a single tunnel). The safety feasibility of this concept is contingent upon use criteria relating to the anticipated volume of traffic, limitations on larger commercial vehicles and tunnel design features including ventilation specific for a bi-directional tunnel and center barriers with an emergency walkway.

However, if Federal Highway Funds are contemplated for funding, the use of a bi-directional tunnel feature may be deemed unacceptable regardless of the design features assumed. Therefore, the following cost estimates also recognize order of magnitude costs for a twin-tunnel section using smaller individual tunnels allowing for uni-directional traffic flow through each tunnel.

Appendix B provides additional and expanded discussion of tunnel system considerations.

## **COST ESTIMATE**

Table 1 provides an order of magnitude cost estimate for the Project if a single bi-directional tunnel is feasible. Table 2 provides an order of magnitude cost estimate if twin uni-directional tunnel system (with smaller tunnels) is used. The confirmation of the required tunnel system will ultimately be subject to future evaluation as described in the "FUTURE WORK TASKS TO ADVANCE THE PROJECT" section of this study.

**TABLE 1****LUALUALEI NAVAL ROAD/KUNIA ROAD CONNECTOR  
COST ESTIMATE FOR SINGLE BI-DIRECTIONAL TUNNEL**

ITEM DESCRIPTION	UNIT PRICE	TOTAL
30,000-linear foot roadway including grading for banks and drainage improvements	\$2,500/LF	\$ 75,000,000
5,200-linear foot bi-directional tunnel (excluding roadway included in item above), including excavation, lining, ventilation, and lighting	\$19,000/LF	\$ 99,000,000
40 acres land acquisition	\$5/Sq. Ft.	\$ 9,000,000
Subtotal		\$ 183,000,000
Contingency (~20%)		\$ 36,000,000
<b>TOTAL</b>		<b>\$ 219,000,000</b>

**TABLE 2****LUALUALEI NAVAL ROAD/KUNIA ROAD CONNECTOR  
COST ESTIMATE FOR TWIN UNI-DIRECTIONAL TUNNELS**

ITEM DESCRIPTION	UNIT PRICE	TOTAL
30,000-linear foot roadway including grading for banks and drainage improvements	\$2,500/LF	\$ 75,000,000
5,200-linear foot twin uni-directional tunnels (excluding roadway included in item above), including excavation, lining, ventilation, and lighting	\$25,000/LF	\$ 130,000,000
40 acres land acquisition	\$5/Sq. Ft.	\$ 9,000,000
Subtotal		\$ 214,000,000
Contingency (~20%)		\$ 43,000,000
<b>TOTAL</b>		<b>\$ 257,000,000</b>

## **STUDY ASSUMPTIONS AND QUALIFICATIONS**

This roadway evaluation has been prepared to evaluate conceptual feasibility and generate a supporting order of magnitude cost estimate. It is intended that this document be used to explore whether funding options are viable. The following items should be programmed into project development:

1. Verification of the soils engineering assumptions of the project based on field testing. This pertains to the overall alignment as well as the tunnel assumptions.
2. Coordination/communication with the affected landowners (the Navy and Campbell Estate). In particular, the Navy's official policy will be that the proposed roadway project is not compatible with the mission of its facility.
3. Community disclosure and input with acknowledgment of archaeological/cultural issues.

The foregoing items have been specifically identified; however, it is implied that additional feasibility assessment as well as complete design and approval processing are also required.

## **FUTURE WORK TASKS TO ADVANCE THE PROJECT**

The following work tasks are identified to advance the Project. Each item includes a budget for the task and estimated time to complete the task:

1. Consultation meeting with the major affected landowners to identify that the Concept Study has provided an order of magnitude cost estimate that merits further feasibility studies and Project development which could lead to actual construction and implementation. The major affected landowners are the Estate of James Campbell (Kunia side of the Waianae Range) and the U.S. Navy (Lualualei side of the Waianae Range).

This meeting is intended to obtain a generally agreed upon broad-based endorsement that if the additional work study steps provide confirmation of the Project's feasibility, there would be no landowner concerns that would prevent ultimate implementation. Conversely, this meeting would also serve as a forum to outline landowner concerns that would need to be reconciled/resolved to allow ultimate construction.

It is anticipated that this meeting would be initiated by City officials and technically supported by the Consultant. The information exchanged would subsequently be used by the City to evaluate the merits of issuing a "Notice to Proceed" with the additional feasibility work tasks.

**FEE TO SUPPORT CONSULTATION MEETING WITH LANDOWNERS:**

None (considered incidental to the Concept Study)

**TIME REQUIREMENT:** 30 days (that required to schedule and  
conduct meeting)

2. Establish use criteria for the Project to validate safe operation parameters.

The use of a single bi-directional tunnel and its safety is directly related to projected traffic volumes, design speeds, vehicle types allowed and features incorporated (i.e., refuge bays to accommodate disabled vehicles and use of center barriers). Use limitations to passenger vehicles, trucks under 2 tons and public transportation (buses) limited to smaller capacity are more favorable for design consideration proposing a bi-directional tunnel.

Heavier use criteria and use of larger vehicles will shift the tunnel design toward two tunnels (smaller) allowing uni-directional traffic.

**FEE FOR USE STUDY/SAFETY CRITERIA ANALYSIS:** \$50,000

**TIME REQUIREMENT:** 90 Days

3. Evaluate alternative tunnel configurations in conjunction with Item 2, above.

Alternative tunnel configurations would include evaluation of a bi-directional tunnel with varying use of such features as refuge bays and different center barrier concepts. Evaluation would also assess the use of two smaller tunnels allowing uni-directional traffic flow.

An additional component of this work phase would also be refined evaluation of the tunnel segment approach roadways to verify the necessary tunnel length.

FEE FOR TUNNEL EVALUATION AND

ROADWAY LAYOUT CONFIRMATION: \$75,000

TIME REQUIREMENT: 90 to 120 days

(NOTE: It is anticipated that this work task would be authorized concurrently with Item 2, above)

4. Perform geologic exploration to support proposed tunnel configuration and alignment identified in Item 3, above. A detailed geological reconnaissance (not including exploratory drilling and lab testing program) is anticipated to be satisfactory to support the findings of Item 3, above. The much more costly drilling and testing program can be postponed to a future (but mandatory) work task.

FEE FOR GEOLOGIC RECONNAISSANCE: \$35,000

TIME REQUIREMENT: 90 to 150 days

5. Ventilation will be a critical component for the tunnel design. A separate and specific analysis is proposed assuming completion of the preceding work tasks indicates the Project is still viable. The study would evaluate two ventilation alternatives and equipment layouts.

FEE FOR VENTILATION STUDY: \$35,000

TIME REQUIREMENT: 60 Days (after completion of Item 4)

6. Historic preservation/cultural issues that may affect the Project should be assessed at an early time frame in the Project development. A preliminary historical record review and preliminary cultural impact assessment should be undertaken to identify potential issues.

FEE FOR PRELIMINARY HISTORIC/CULTURAL

ISSUES IDENTIFICATION: \$30,000

TIME REQUIREMENT: 90 Days (conducted concurrently with Items 2, 3, 4, or 5, above)

The total fee for work tasks 1 through 6 is anticipated to be \$220,000 to \$250,000 and the time frame to complete is 180 to 240 days from the notice to proceed. While there are future (and substantive) work tasks to be completed, it is premature to assign fees to these future work tasks. Future work tasks will include:

- A. EIS Clearance (Chapter 343 and NEPA)
- B. Detailed Geologic Evaluation (Field borings and laboratory analysis)
- C. Ground Topographic Survey
- D. Preliminary Engineering Design using the information from Items B and C, above, detailed hydrologic and hydraulic evaluation of drainage considerations, evaluation of temporary access roads and their designs as well as refined tunnel design.

- E. Final Design and processing for approval with appropriate governmental agencies.

Completion of Items A through E above will require fees estimated to be between \$10 and \$15 Million Dollars and the time requirement could easily be 3 to 5 years. It is further anticipated that a 3 to 4-year construction period would be required.





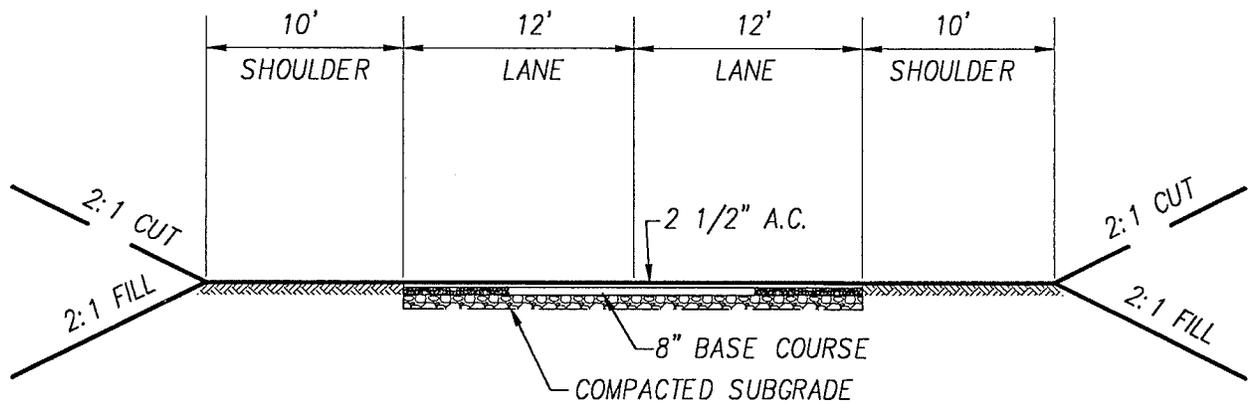


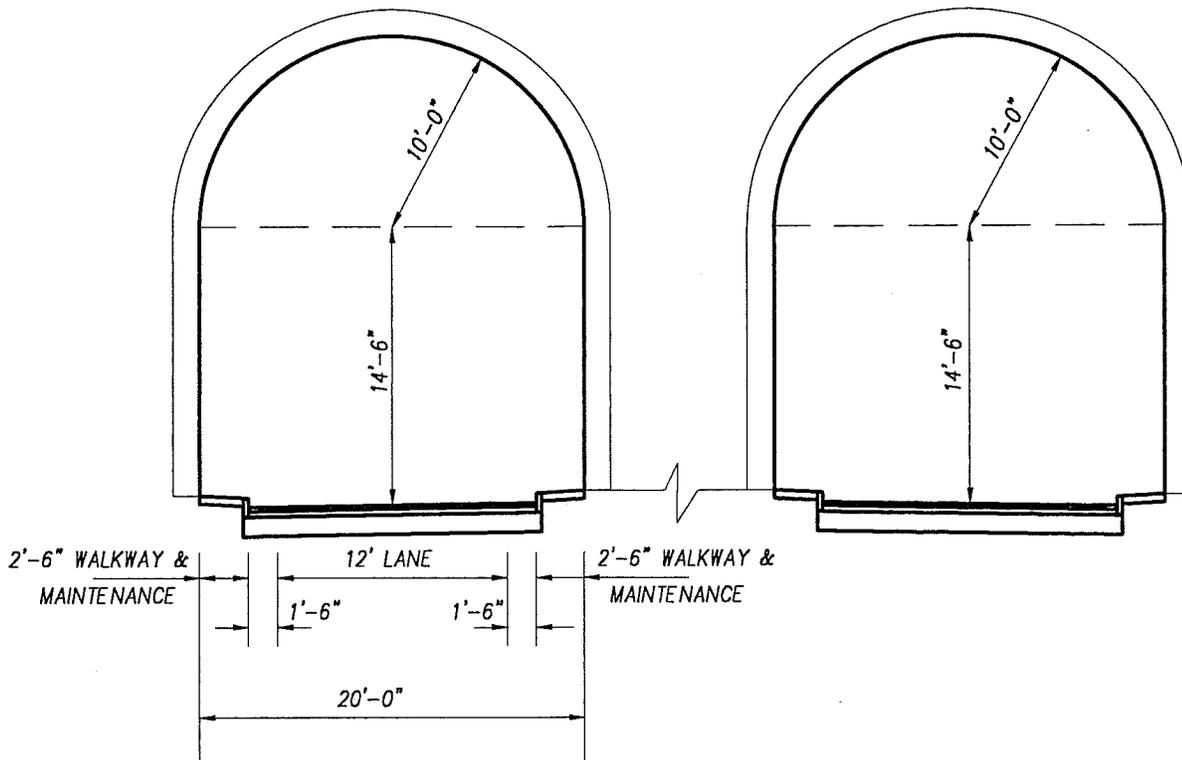
FIGURE 2


 GRAY, HONG, BILLS, NOJIMA & ASSOCIATES, INC.  
 CONSULTING ENGINEERS  
 841 BISHOP STREET SUITE 1100

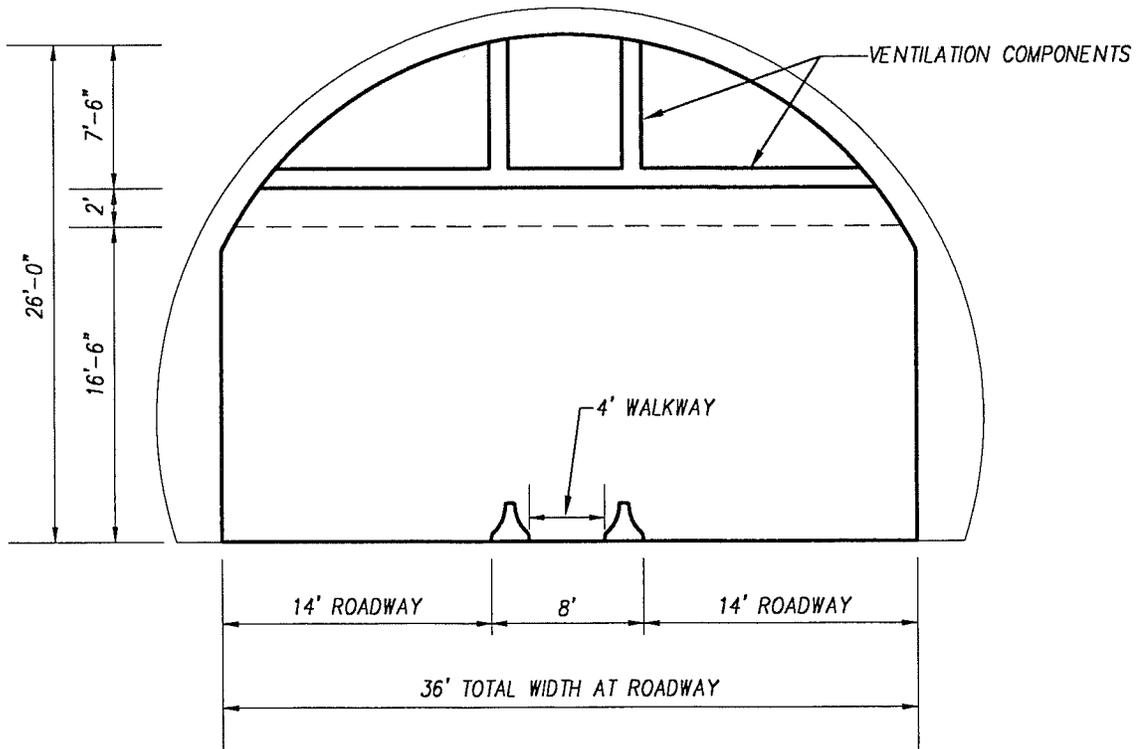
LUALUALEI NAVAL ROAD/  
KUNIA ROAD CONNECTOR

TYPICAL ROADWAY SECTION

SCALE: 1" = 10'-0"

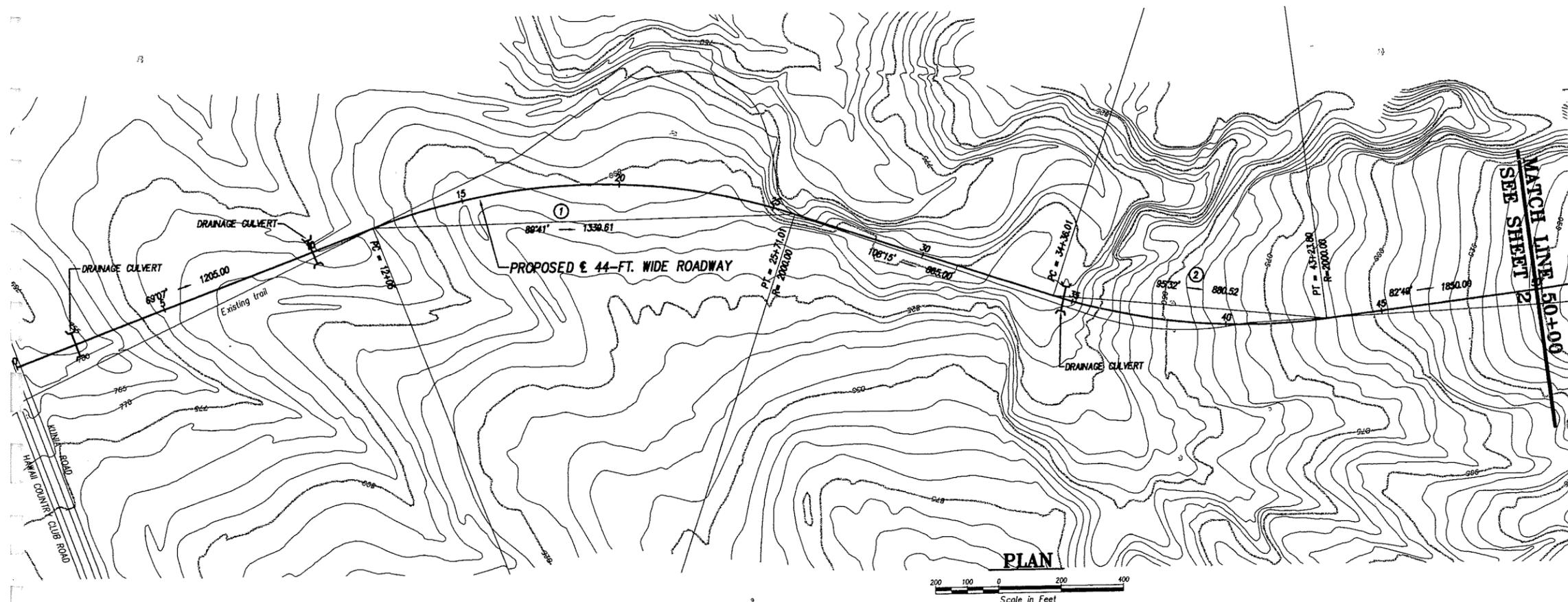


**SINGLE LANE UNI-DIRECTIONAL TUNNEL SYSTEM**



**TWO-LANE BI-DIRECTIONAL TUNNEL SYSTEM**

SCALE: NOT TO SCALE	<b>TYPICAL TUNNEL SECTIONS</b>	 <b>Gray-Hong-Bills-Nojima &amp; Associates, Inc</b> CONSULTING ENGINEERS 841 Bishop Street Suite 1100	<b>FIGURE</b>  <b>3</b>
CAD DRAWING: 2810FIG3			
DATE: AUGUST 28, 2001			

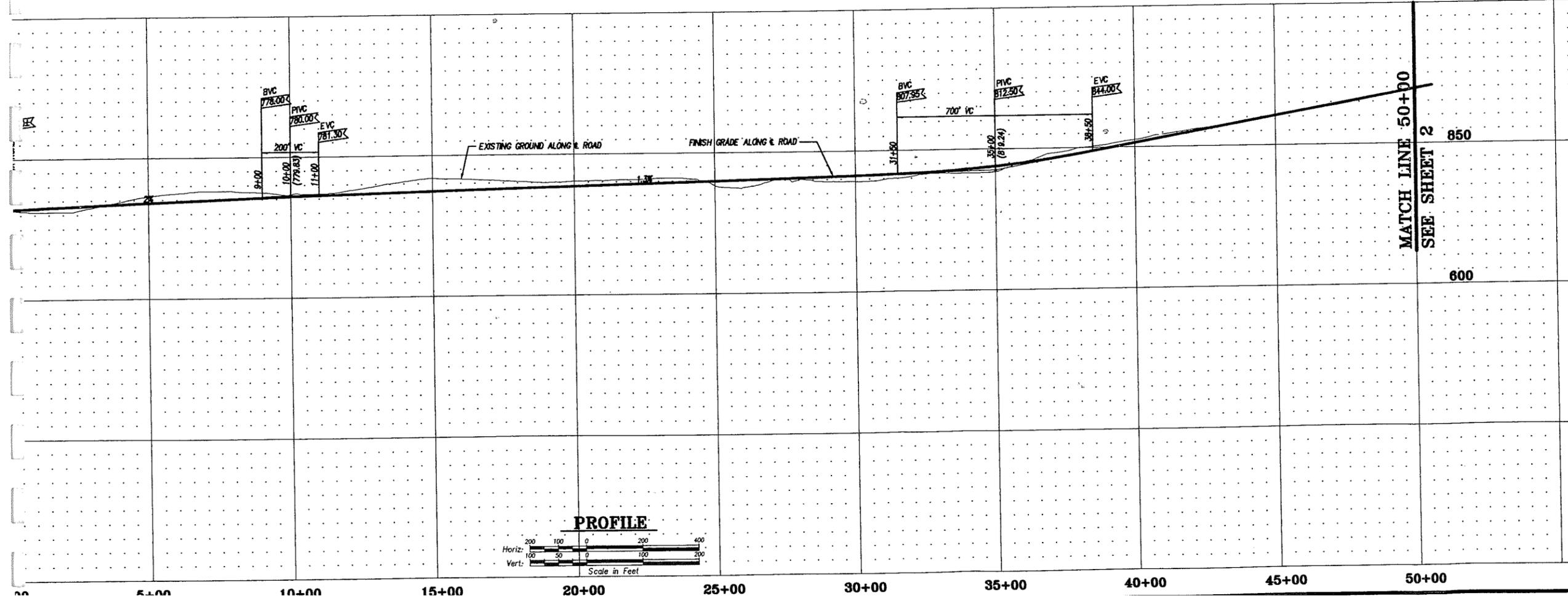


TRUE NORTH  
Scale 1 in. = 200 ft.

**☉ CURVE DATA**

	①	②
Δ	39°08'	25°28'
Δ/2	19°34'	12°43'
R	2000.00	2000.00
T	710.88	451.33
Ch	1338.61	880.52
Lc	1368.01	887.79

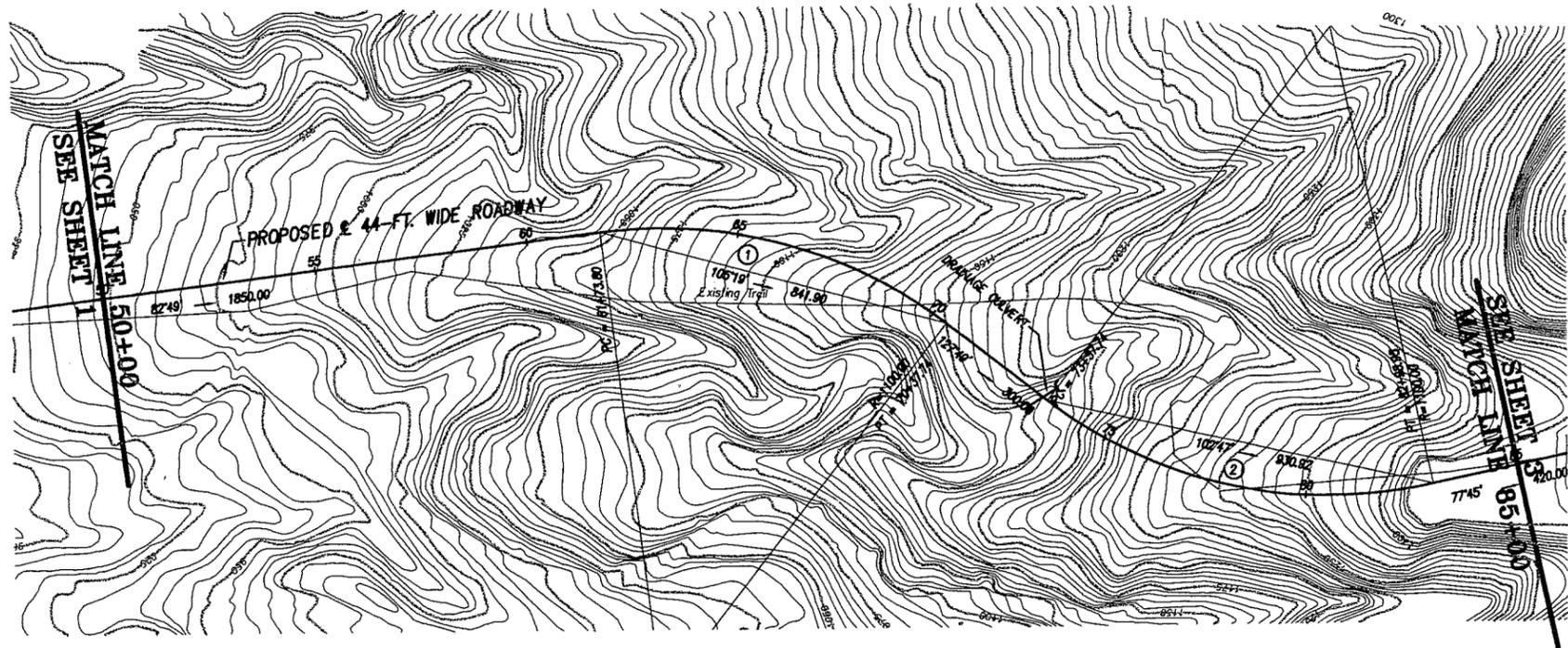
- LEGEND**
- DRAINAGE CULVERT
  - DRAINAGE INTERCEPTOR
  - EXISTING CONTOUR
  - EXISTING TRAIL



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**LUALUALEI NAVAL ROAD/  
KUNIA ROAD CONNECTOR**

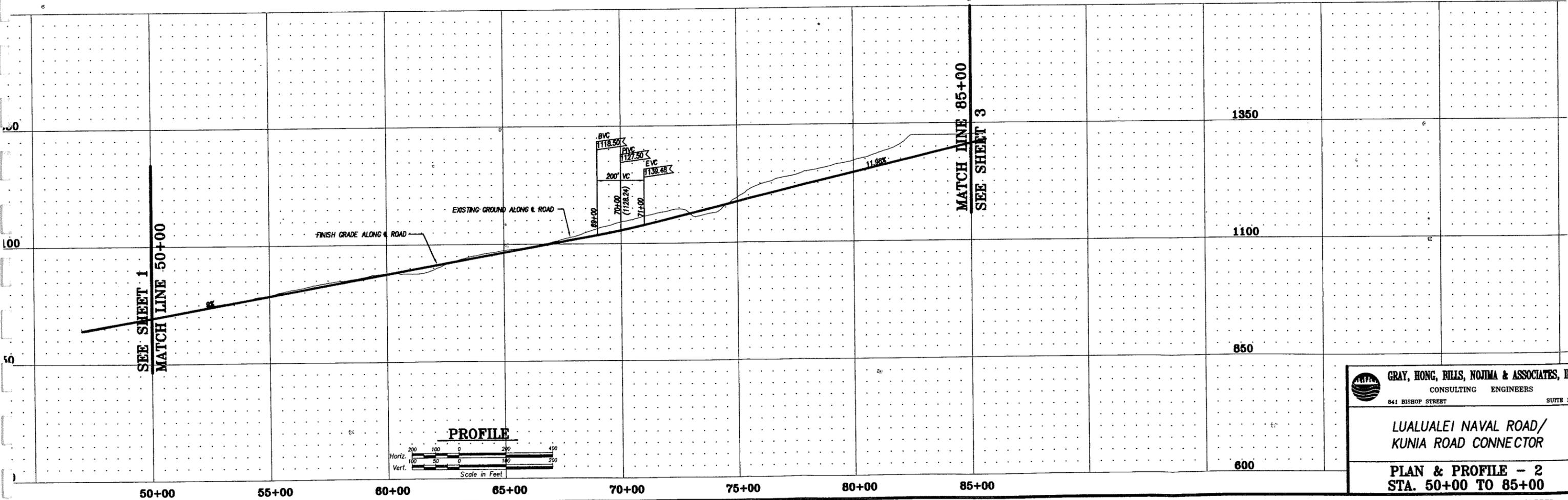
**PLAN & PROFILE - 1  
STA. 0+00 TO 50+00**



**¢ CURVE DATA**

	①	②
$\Delta$	45°00'	50°04'
$\Delta/2$	22°30'	25°02'
R	1100.00	1100.00
T	455.63	513.72
Ch	841.90	830.92
Lc	863.94	961.21

- LEGEND**
- DRAINAGE CULVERT
  - DRAINAGE INTERCEPTOR
  - EXISTING CONTOUR
  - EXISTING TRAIL



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**PLAN & PROFILE - 2  
 STA. 50+00 TO 85+00**

SHEET 2 OF 6 SHEETS



PROPOSED 44-FT. WIDE ROADWAY

¢ CURVE DATA

	①	②
Δ	1357'00"	52'00"
Δ/2	678'30"	26'00"
R	1100.00	1100.00
T	134.58	536.51
Ch	267.16	964.42
Lc	267.82	998.33

TRUE NORTH  
Scale 1" = 200 ft.

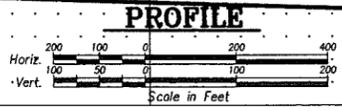
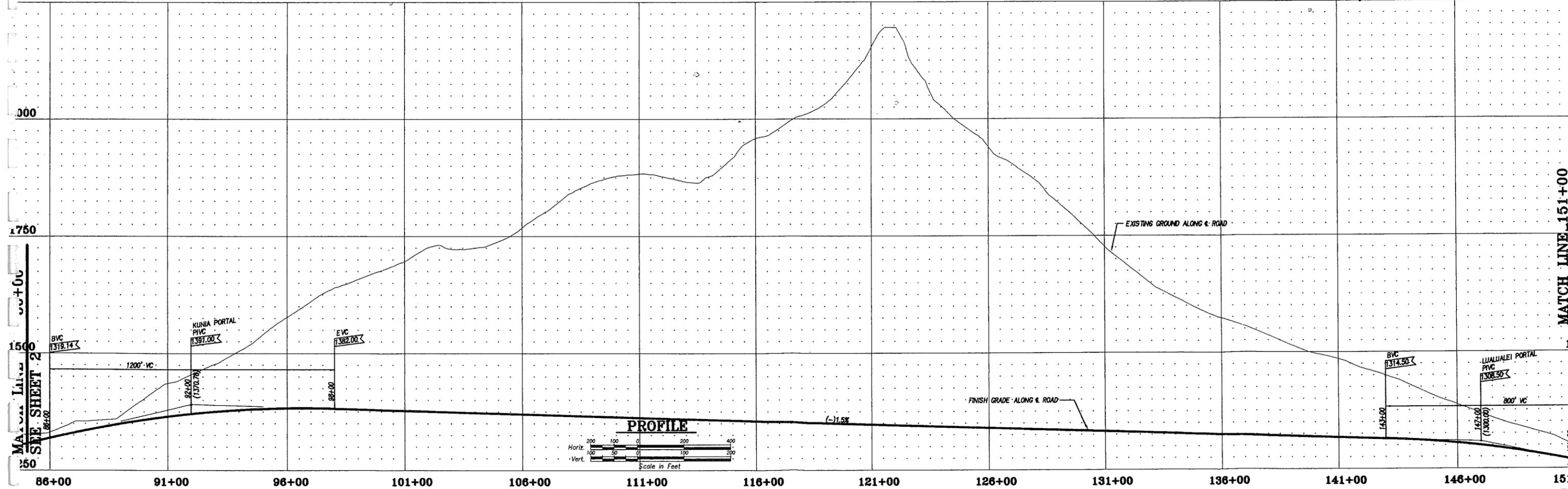


- LEGEND**
- ( — ) — DRAINAGE CULVERT
  - ( — ) — DRAINAGE INTERCEPTOR
  - 875 — EXISTING CONTOUR
  - — — EXISTING TRAIL

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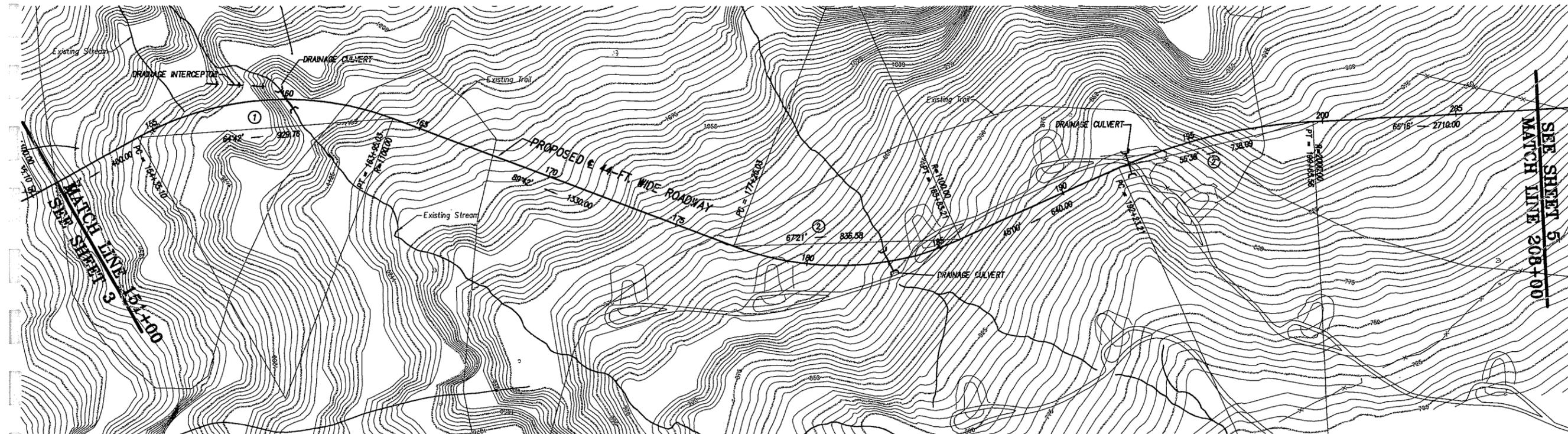
**LU'ALUALEI NAVAL ROAD/  
KUNIA ROAD CONNECTOR**

**PLAN & PROFILE - 3  
STA. 85+00 TO 151+00**



MATCH LINE SEE SHEET 2

MATCH LINE 151+00



SEE SHEET 5  
MATCH LINE 208+00

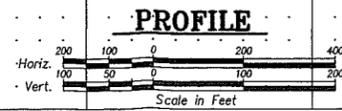
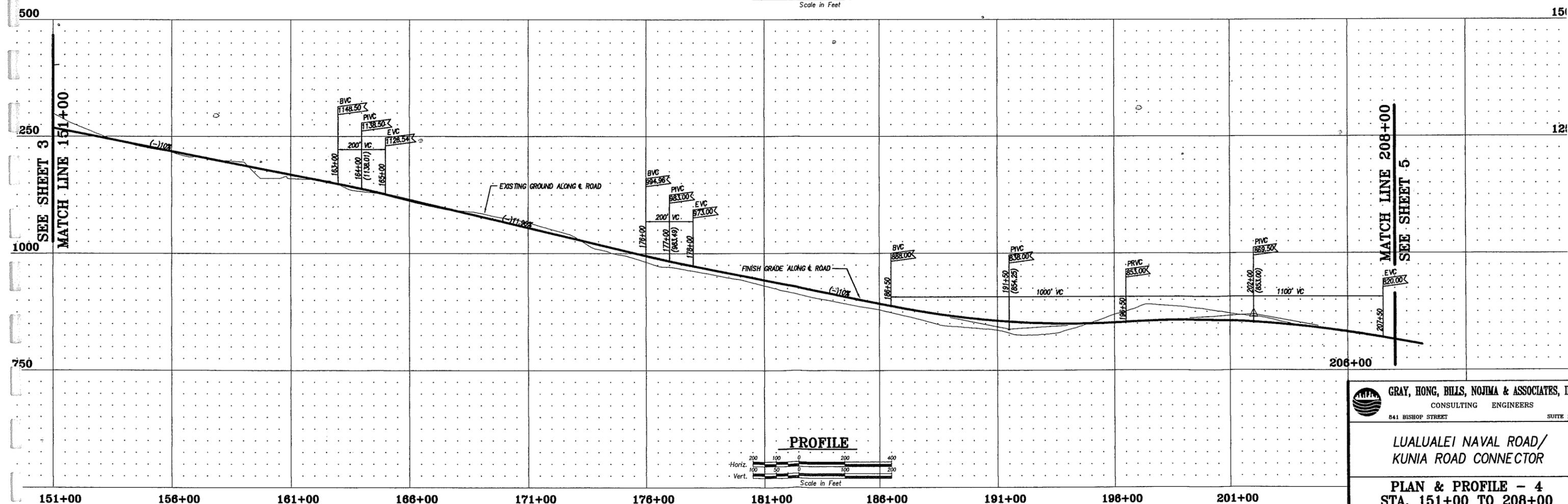
SEE SHEET 3  
MATCH LINE 151+00

ε CURVE DATA

	①	②	③
Δ	50'00"	44'42"	21'16"
4/2	25'00'	22'21'	10'38'
R	1100.00	1100.00	2000.00
T	512.94	452.26	375.49
Ch	929.76	836.58	738.09
Lc	959.93	858.18	742.35

LEGEND

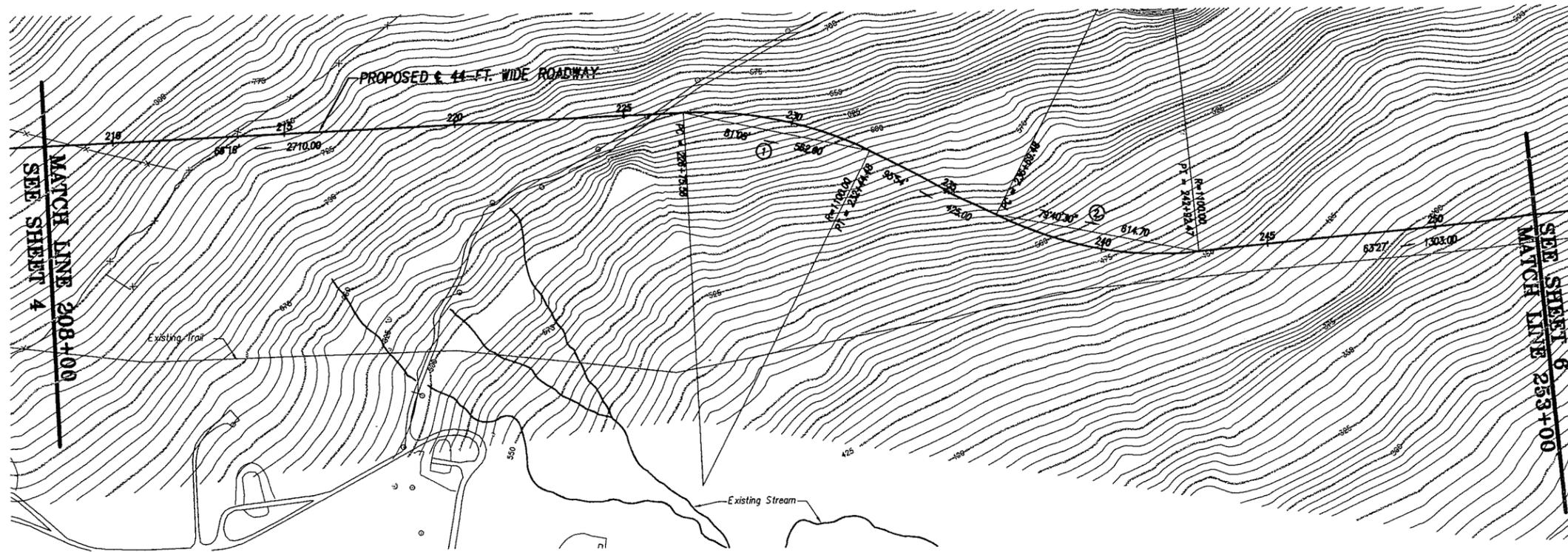
- DRAINAGE CULVERT
- DRAINAGE INTERCEPTOR
- EXISTING CONTOUR
- EXISTING TRAIL



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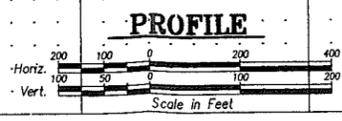
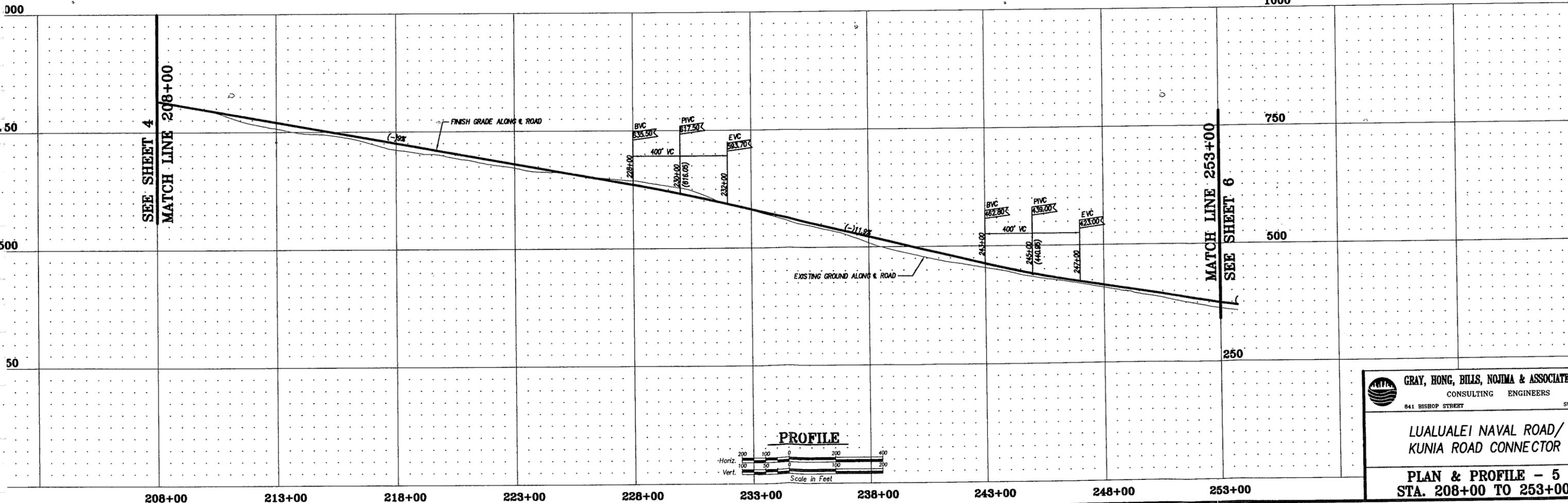
PLAN & PROFILE - 4  
STA. 151+00 TO 208+00



**☐ CURVE DATA**

	①	②
Δ	29°38'	32°27'00"
∠/2	14°49'	16°13'30"
R	1100.00	1100.00
T	290.97	320.10
Ch	562.60	614.70
Lc	568.92	623.00

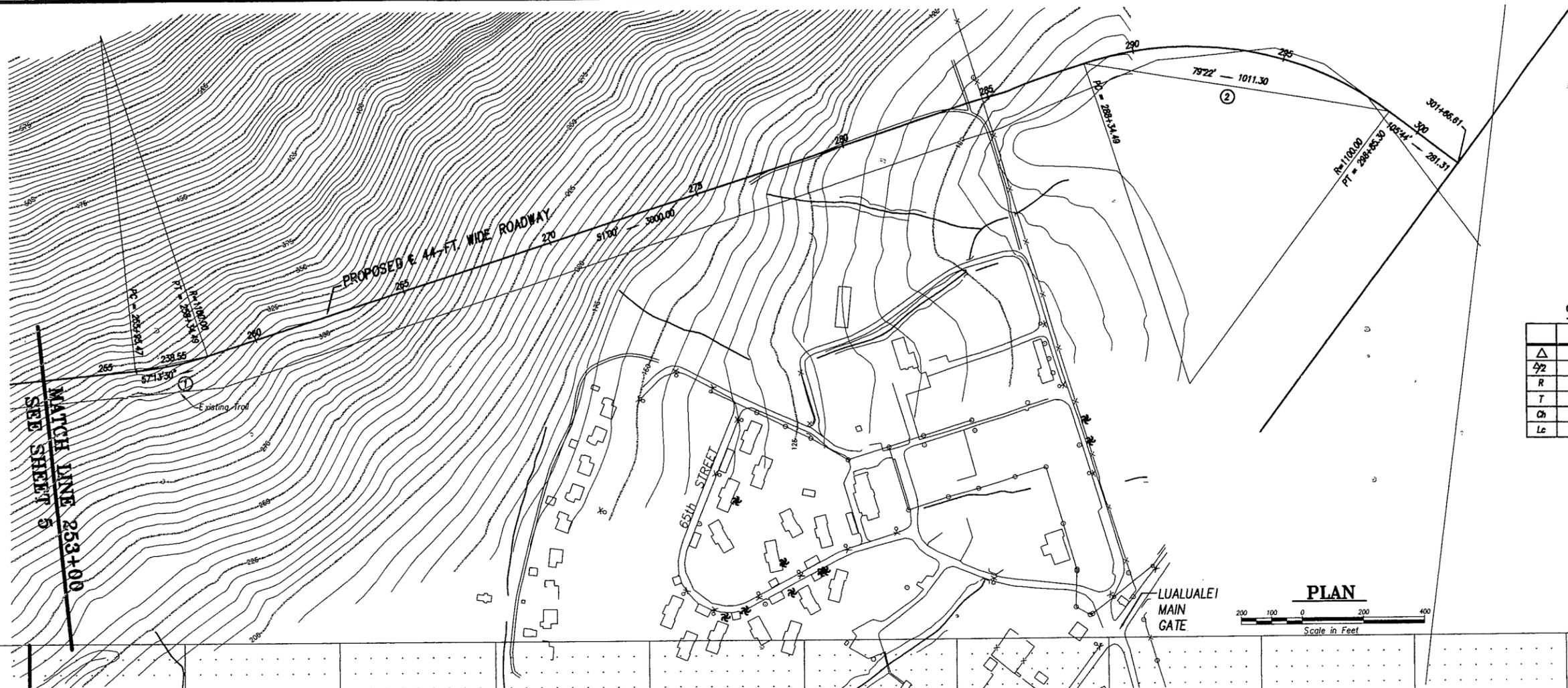
- LEGEND**
- DRAINAGE CULVERT
  - DRAINAGE INTERCEPTOR
  - EXISTING CONTOUR
  - EXISTING TRAIL



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**LUALUALEI NAVAL ROAD/  
KUNIA ROAD CONNECTOR**

**PLAN & PROFILE - 5**  
**STA. 208+00 TO 253+00**

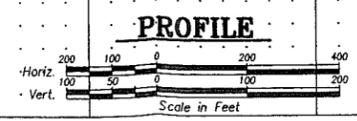
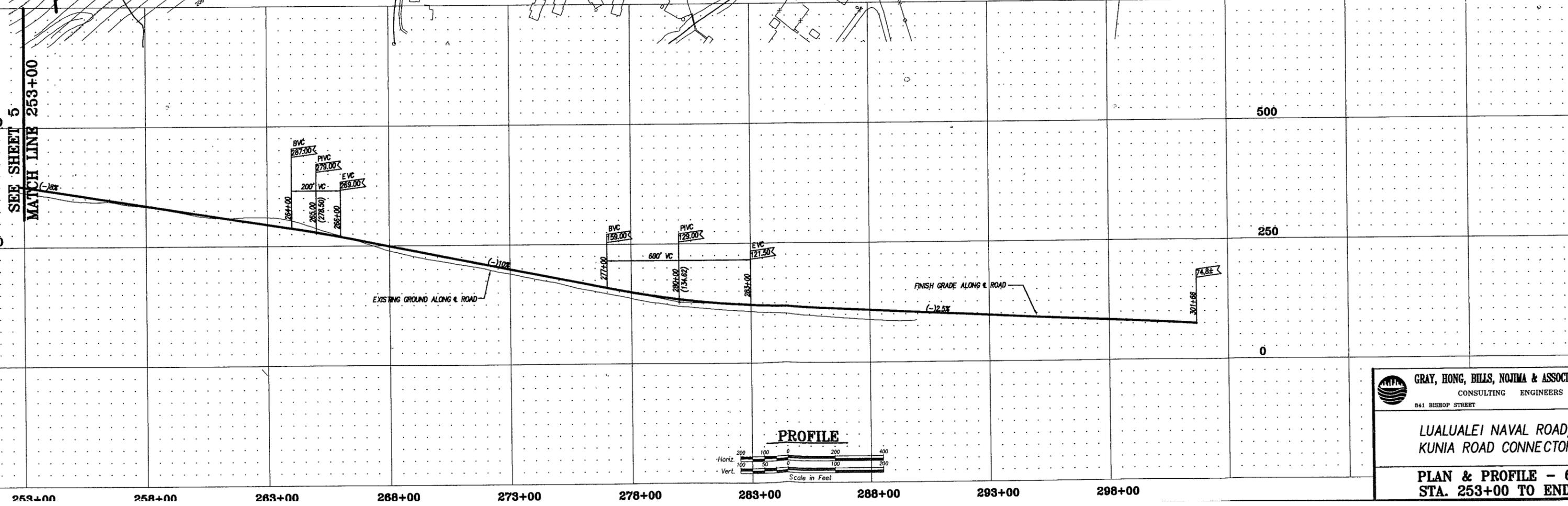
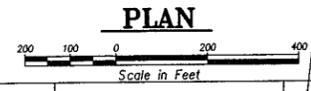


**ε CURVE DATA**

	①	②
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Δ/2	6'13'30"	27'22"
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T	119.98	569.37
Ch	238.55	1011.30
Lc	239.02	1050.80



- LEGEND**
- DRAINAGE CULVERT
  - DRAINAGE INTERCEPTOR
  - EXISTING CONTOUR
  - EXISTING TRAIL



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**LUALUALEI NAVAL ROAD/  
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**PLAN & PROFILE - 6  
STA. 253+00 TO END**

## **APPENDIX A**

**SOILS ANALYSIS:  
GEOTECHNICAL CONSULTATION  
PROPOSED LEEWARD TUNNEL  
LUALUALEI, OAHU, HAWAII**

**Prepared By**

**MASA FUJIOKA & ASSOCIATES  
Environmental, Geotechnical, Hydrogeological Consultants  
99-1205 Halawa Valley Street, Suite 302  
Aiea, HI 96701-3281  
Phone: (808) 484-5366  
Fax: (808) 484-0007**



# MASA FUJIOKA & ASSOCIATES

A PROFESSIONAL PARTNERSHIP

ENVIRONMENTAL • GEOTECHNICAL • HYDROGEOLOGICAL CONSULTANTS

99-1205 Halawa Valley Street, Suite 302 • Aiea, Hawaii 96701-3281  
Phone 808 484-5366 • Fax 808 484-0007

July 30, 2001

Gray Hong Bills Nojima & Associates, Inc.  
Davies Pacific Center  
841 Bishop St., Suite 1100  
Honolulu, Hawaii 96813

Fax No. 531-8018

Attn: Mr. David Bills, P.E.

Subject: Geotechnical Letter Report  
Geotechnical Consultation  
Proposed Leeward Tunnel  
Lualualei, Oahu, Hawaii

Dear Mr. Bills:

Masa Fujioka & Associates (MFA) is pleased to submit this letter report on geotechnical consultation for the subject project.

We understand that Gray Hong Bills Nojima is undertaking a planning level study of alternate routes into the Leeward side of Oahu. One possible alternative would be a cross Waianae range tunnel. The tunnel would link an existing cane haul road in the Kunia area to an existing military road in Lualualei. The approximate tunnel parameters would be:

1. Tunnel length of 5200 feet.
2. Tunnel grades will not exceed 5 percent.
3. Straight tunnel alignment.
4. The roadway leading to the tunnel will be two-12 foot travel lanes with an 8 foot shoulder on each side. The tunnel does not have to have the whole 8 foot wide shoulder if not considered necessary.
5. Roadway grades will not exceed 12 percent, to enable use of Asphaltic Concrete (AC) pavements.

At this time, access to the alignment of the proposed tunnel and approaches is limited by the ground topography and lack of access to the military (leeward) side of the proposed alignment. Based on the above considerations, we proposed to conduct a study based on available geological and soils data.

To develop a conceptual tunnel design and cost estimate, we engaged Dr. William Hansmire of Jacobs Associates (San Francisco) to work with us as a subcontractor. While previously with Parson Brinckerhoff Quade and Douglas, Dr. Hansmire served as the principal geotechnical and tunneling designer for the H3 tunnel.

Gray Hong Bills Nojima & Associates, Inc.  
July 30, 2001  
Page 2

We understand that possible soil instability in Lualualei is of concern for the tunnel approach road. MFA reviewed available soils and geological information and previous studies and projects in the general area to study this potential issue.

### **SCOPE OF WORK**

The following scope of work was proposed and performed:

1. **Data Review**

MFA reviewed available geological and soils information and prepared a geological and soils summary of the alignment.

2. **Engineering Analysis**

Based on the available information we conducted engineering analyses and developed the following preliminary information:

- a. Preliminary roadway grading and stability recommendations.
- b. Preliminary assessments of roadway pavement section requirements.
- c. Plotting of available geological and soils information along the tunnel approach and tunnel alignment.
- c. Conceptual tunnel design and cost estimate.

3. **Report**

We present our findings and recommendations in this geotechnical consultation letter report.

### **FINDINGS**

#### **GEOLOGY AND SOILS DATA REVIEW**

The location of the proposed tunnel and approach roads are indicated on the Map of Area, Figure 1. Soils along the approach road alignments have been mapped by the Soil Conservation Service, and are depicted on Figure 2. A Geologic Map and a Cross Section along the tunnel, based on available geologic information, are depicted on Figure 3.

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### General Geology of Waianae Volcano:

The Pohakea Pass proposed tunnel alignment area straddles the crest of the Waianae Range, the erosional remnant of Waianae Volcano on the western and older half of the island of Oahu, Hawaii. The remnant volcanic edifice includes good exposures of relatively unaltered lavas from both shield and post-shield stages of Hawaiian Volcanism (Guillou, et al., 2000).

Pohakea Pass is located at the upper South Rift Zone, approximately 2.5 miles southeast of Puu Kailio. The South Rift Zone is only loosely defined due to a lack of dike exposures and randomly oriented eruptive vent features (Presley, 1997). Zbinden (1984) did not observe dikes on the Lualualei side of Pohakea Pass, at the crest of the ridge between Palikea and Pohakea Pass, or in the Palehua Member of Pohakea Pass; Stearns (1938), however, did map dike structures immediately north of the gully descending from Pohakea Pass on the Waianae side (Figure 1). A faulted area of Nanakuli Ridge, immediately southwest of Pohakea Pass, is likely a pit crater associated with late flank-stage/rift zone volcanism, according to Sinton (1979).

Dikes are not evenly distributed about the volcano, but are concentrated in the rift zones and in the caldera region. Dikes are randomly oriented in the vicinity of the caldera region, generally defined by shallow-dipping to horizontal caldera-filling flows and by the location of normal faults. Dikes are generally oriented parallel to rift zone structures. A triple rift zone structure (Northeast, Northwest, and South Rift Zones) has been designated by most investigators with respect to the caldera located broadly about Lualualei Valley. Puu Kailio immediately west of Kolekole Pass (northwest of Pohakea Pass -- see Figure 1) is considered to be located at a major vent of Waianae caldera's volcanic activity. Talus breccias with significant amounts of ash, fault contacts, and abundant dikes are present in this area (Presley, 1997). It is likely that the area presently observed to have caldera-filling lavas is the time-integrated sum of several calderas and pit craters (Zbinden, 1984).

The oldest member of the Waianae Volcanics is the Lualualei (shield-building) tholeiitic lava (Guillou, et al., 2000), consisting of thin-bedded pahoehoe and a'a flows found mostly at the bases of ridges, but also located up to a maximum elevation of 1800 feet above MSL (Zbinden, 1984). The flows dip away from the caldera region, to 15 degrees or more. Radiometric dating and magnetic reversal studies confirm an eruption period ranging from 3.9 Ma to 3.5 Ma (Guillou, et al., 2000). Few tuffs or ashes and no paleosols have been observed within this member (Zbinden, 1984).

An angular unconformity, sometimes accompanied by talus or soil, separates the Lualualei Member from the overlying Kamaileunu Member. The 1800-foot thick Kamaileunu sequence formed during the caldera-filling stage of volcanic activity and consists of thicker flows that are proportionately more a'a than pahoehoe type, relative to Lualualei flows. Most of the

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caldera-filling flows either gently dip away from rift zone axes or are horizontal (Zbinden, 1984). Kamaileunu basalts are tholeiitic, transitional, and alkalic basalts. The silica-rich Mauna Kuwale Rhyodacite Flow, located several miles northwest of Pohakea Pass, is included in this eruptive sequence (Presley, et al., 1997). Kamaileunu basalts erupted over a period of about 450 ka (Guillou, et al., 2000).

In some places the contact between Kamaileunu and overlying Palehua Member flows is marked by a soil layer. This is the case at Pohakea Pass, where a horizon of up to three feet of soil is located (Zbinden, 1984). The overlying Palehua Member marks the end of the caldera-filling stage (or the start of the post-shield stage) and the beginning of the alkalic cap stage of Waianae volcanism. The Palehua Member consists of typically more massive, thick, and lighter colored flows than those from the previous stages. Palehua basalts are mostly bluish to light gray hawaiite basalt that is aphyric or contains rare small olivine grains. Ground mass textures are predominantly trachytic, and in the field, many outcrops exhibit foliation due to preferential weathering of the flow-aligned matrix crystals (Presley, et al., 1997). The eruptive sequence which produced the Palehua Member lasted approximately 80 ka (Presley, et al., 1997).

A major unconformity locally separates Palehua hawaiites from the youngest sequence of the Waianae Series, the Kolekole Member (Guillou, et al., 2000). At Kolekole Pass, a polymict conglomerate (a mudflow deposit) unconformably overlies weathered Kamaileunu Member lavas and dikes and underlies Kolekole Member basalt flows. The mudflow contains clasts from a wide range of lithologies, including Palehua Member hawaiite. In the southern part of the volcanic complex, a crystalline ash layer nearly a foot thick separates Kolekole from Palehua Member basalts. In other areas the oldest Kolekole Member basalts veneer Palehua Member hawaiites conformably (Presley, et al., 1997).

The Kolekole Member of the Waianae Volcanic Series is the youngest unit of the Series, and was deposited during eruptions which began which began some 2.9 million years ago. Kolekole Volcanics consist of flows and vent deposits of mostly olivine-phyric alkalic basalts, commonly containing xenoliths of more mafic dunite and gabbro, and inclusions or xenoliths of pyroxene xenocrysts. The pyroxenitic inclusions or xenoliths are typically bluish to dark gray, and the presence of 1-3mm diameter olivine phenocrysts easily makes them easy to distinguish from hawaiites in the field (Presley, et al., 1997).

### **Differential Erosion on Waianae Volcano**

Although the leeward side of Oahu is relatively dry, erosion on the western side of the crest of the Waianae Range is much more pronounced than on the eastern side. It is hypothesized that the eastern wall of the caldera gave way, during the shield-building phase of volcanic activity, such that subsequent eruptions spilled onto the eastern slopes of the volcano and filled in the erosional features (Macdonald, et al., 1983). The remaining western rim of the

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caldera would have prevented flows from similarly coating the leeward slopes, exposing them to a much longer period of erosion. Furthermore, it is believed that the earlier rates of erosion would have been much more dramatic than those witnessed today, given that Waianae volcano was present prior to and during the early formation of Koolau volcano, allowing for direct exposure to the trade wind moisture at much higher elevations and greater rainfall rates (Macdonald, et al., 1983).

Lualualei is a broad amphitheater-headed valley on the west side of the Waianae Range. Lualualei is in a late stage of valley development. The flat valley floor covers about 14 square miles. Coral reefs and near-shore sediments were deposited on most of the valley floor during historical higher stands of the sea (Macdonald, et al., 1983). Recent studies suggest that a catastrophic slide, called the Waianae Slump, formed the large amphitheater of Lualualei Valley and associated landslide deposit which dominates the near shore region west of Waianae Volcano (Presley, et al., 1997).

#### **Geologic Cross-Section along the Waianae Tunnel Alignment at Pohakea Pass**

The presently proposed eastern portal of the tunnel is located at 1,400 feet above MSL on the Schofield/Kunia side of Pohakea Pass, at the approximate contact between consolidated non-calcareous sediments (older alluvium washed downslope) and basalt/tuff beds of the Kamaileunu (caldera-filling) Member of the Waianae Series (Figure 3 -- cross-section of tunnel alignment). Therefore, it is likely that such sediment layers and weathered basalt (ranging from tholeiitic to mildly alkalic geochemistry) will be initially encountered along the eastern end of the tunnel excavation.

The Kamaileunu Member is 1,800 feet thick at Kolekole Pass. It likely extends along nearly the entire tunnel alignment toward the Lualualei Portal. Interlayered flows of a'ā and pahoehoe dipping up to 25 degrees towards Schofield/Kunia are likely to be encountered along the tunnel grades. It is also likely that dike formations will be encountered along grade. Despite the fact that few dikes are observed along exposures at Pohakea Pass, it is well-documented that dike abundance increases toward the rift zone and (especially the) caldera regions, and that dikes tend to be oriented parallel to rift zone structures at depth. Therefore, it is assumed that several dikes will be encountered approximately perpendicular to grade upon the approach to the crest of the Pass, near the beginning of the South Rift Zone. These dikes are generally nearly vertical (to within 20°) and less than three feet thick perpendicular to strike. With distance towards the caldera region near Lualualei Portal, however, the number of dikes should increase and orientation should become more random, complicating the geologic structure at the west end of the tunnel. It has also been proposed that the focus of dike emplacement has remained stationary over time, and that older dikes have migrated due to displacement seaward with time (Zbinden, 1984). This suggests it is possible that there are structural implications (faulting) associated with such displacement at depth on the seaward side of Pohakea Pass.

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Consolidated alluvium at the proposed Lualualei Portal may have buried the contact between volcanic members, and perhaps buried key structural features (faults, eruptive vents, synclines, etc.). Kolekole Pass to the north of the tunnel alignment is located within the presumed caldera; it has zones of faulting and breccia deposits (Figure 3 inset from Stearns, 1938). Pohakea Pass is estimated to be located a few thousand feet east of the caldera-proper, well within relatively uniform flow layers of Kamaileunu basalts; however, the boundary of the caldera is not well defined, and the tunnel excavation terminating at Lualualei Portal could potentially encounter fault/breccia zones, or simply a contact between Kamaileunu basalts and Lualualei Member flows. (There are fault contacts mapped at the 600 feet contour interval, less than two miles west of Pohakea Pass.) The Lualualei Member basalts, which often contain xenoliths of more mafic material, tend to have more pahoehoe than a flows relative to the Kamaileunu Member basalts. Very few tuff, ash beds, or paleosols are observed within the older Lualualei basalts (Zbinden, 1984).

Tunnel excavation near the Lualualei Portal will encounter a contact (or transition zone) between consolidated sediments and basalts. An unknown thickness of consolidated alluvium is present at the proposed Lualualei Portal.

It is unlikely that the (mostly a flows of) Palehua Member hawaiiite (the upper alkalic, post-shield cap) or uppermost Kolekole Member basalts will be encountered along the tunnel excavation, unless dramatic faulting has displaced it downward along the Waianae side of the pass.

### **Surface Soils at Approach Alignments**

Surface soils along the approach alignments likely to be encountered are listed in order of appearance from Kunia Road in Wahiawa to the terminus of Dent Street in Lualualei Valley (Figure 2) (Note: surface soils above the tunnel alignment are not included).

#### **KyA (Kunia Road terminus and lower Kunia approach)**

##### Kunia Silty Clay (0-3% slope)

Kunia soils are well-drained, developed from old alluvium, and occur on upland terraces and fans on Oahu at elevations ranging from 700 to 1,000 feet above MSL. Mean annual rainfall is 30 to 40 inches, mostly from November to April. They are geographically associated with Kolekole, Lahaina, and Wahiawa soils. Most areas are cultivated (without natural vegetation) and are used for sugarcane, pineapple, home sites, and military reservations.

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KyA occurs on broad, smooth slopes and include small areas of Kolekole soils and small areas of red, clayey soils at the lower elevations. A representative profile is detailed on an attached sheet. It includes a surface layer of dark reddish-brown silty clay about 22 inches thick. The subsoil is 40 to 71 inches thick, and is dark reddish-brown silty clay and silty clay loam with subangular blocky structure. The substratum is dark reddish-brown gravelly silty clay. Manganese concretions occur throughout the series. Permeability is moderate and runoff slow, with erosion hazard no more than slight. Available water capacity is about 1.7 inches per foot of soil. Roots penetrate to five feet of depth or more.

**KyB** (lower Kunia approach)

Kunia Silty Clay (3-8% slope)

Same as above only steeper; runoff is slow, erosion hazard is slight. KyB includes small areas of nearly level soils and small areas of Kolekole soils.

**KuB** (lower Kunia approach)

Kolekole Silty Clay Loam (1-6% slope)

Kolekole series consists of well-drained soils developed in old gravelly alluvium mixed with volcanic ash, occurring on gently sloping to moderately steep uplands of Oahu ranging from 500 to 1,200 feet (i.e. the windward slopes of the Waianae Range). Annual rainfall amounts to 35 to 50 inches, mostly between the months of November and April. Kolekole soils are geographically associated with Kunia, Mahana, and Wahiawa soils, and are generally used for agricultural purposes (cane, pineapple, pasture). Natural vegetation consists of guava, lantana, bermudagrass, and Natal redtop.

KuB occurs on smooth slopes and includes small areas of Kunia and Mahana soils, small eroded spots, and steep side slopes along drainage ways. The surface layer is dark reddish-brown silty clay loam about 12 inches thick. It overlies 48 inches of subsoil that is dark reddish-brown silty clay loam and silty clay having subangular and angular blocky structure. Substratum is old gravelly alluvium. A compact, panlike layer typically occurs at 24 to 40 inches depth within the series. Permeability is moderately rapid to this panlike layer, and moderate in compact subsoil; runoff is slow, and erosion hazard is slight. Available water capacity is about 1.3 inches per foot of soil, and roots are restricted by the compact layer.

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**HLMG** (midsection and upper Kunia approach)

Helemano Silty Clay (30-90% slope)

These well-drained soils, developed in alluvium and colluvium derived from basic igneous rock, occur on alluvial fans and colluvial slopes on the sides of gullies on Oahu at elevations ranging from 500 to 1,200 feet. Slopes are generally very steep, and average annual rainfall is mostly 30 to 60 inches, but ranges to 75 inches at higher elevations. Helemano silty clay soils are used for pasture, woodland, and wildlife habitat. Natural vegetation includes bermudagrass, Christmas berry, eucalyptus, Formosa koa, guava, Japanese tea, Java plum, and koa haole.

HLMG includes small areas of Lahaina and Molokai soils, and small areas of rock outcrop, steep stony land, and eroded spots. The surface layer is dark reddish-brown silty clay about 10 inches thick, overlying about 50 inches of dark reddish-brown and dark-red silty clay subsoil having subangular blocky structure. Substratum is soft, highly weathered basalt. Permeability is moderately rapid, runoff is medium to very rapid, and erosion hazard is severe to very severe.

**KuC** (upper Kunia approach)

Kolekole Silty Clay Loam (6-12% slope)

Same as KuB (above) except steeper, such that runoff is medium and erosion hazard is moderate. Workability is slightly difficult because of the slope.

**McC2** (upper end of Kunia approach and entrance to Kunia Portal)

Mahana silty clay loam. 6-12% slopes. eroded

The Mahana series consists of upland, well-drained soils that are gently sloping to steep. Annual rainfall is 30 to 45 inches. Mahana soils are geographically associated with Kolekole soils on Oahu. These soils are used for pasture, woodland, wildlife habitat, irrigated sugarcane, and water supply. Natural vegetation includes puakeawe, aalii, ricegrass, molassesgrass, silver oak, yellow foxtail, lantana, joe, Japanese tea, passion flower, and associated plants.

McC2 is basically an eroded version of Mahana silt loam with 6 to 12 percent slopes (MaC). MaC occurs on ridge tops and moderately sloping uplands. A representative profile of the approximately seven inches thick surface layer is dusky-red to dark reddish-brown silt loam with subangular blocky structure; erosion has removed most of this layer from McC2, leaving the texture of the subsoil at the surface. MaC subsoil is about 41 inches thick, consisting of dark-red to dusky-red silt loam and silty clay loam. Substratum is compact silty clay loam.

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Permeability is moderately rapid, runoff is slow, and erosion hazard is slight for Mahana silt loam. Available water capacity is about 1.5 inches per foot of soil. Roots penetrate to depths of five feet or more in some places.

rST (Most of Lualualei approach: west end of tunnel alignment, including Lualualei Portal, to beginning of Dent St.)

#### Stony Land

Stony Land occurs mainly in valleys and on side slopes of drainage ways located on the Waianae coastal region of Oahu. Boulders and stones deposited by water and rockfall make up most of the series on slopes ranging from five to 40 percent, at elevations from nearly sea level to 500 feet (sic) above MSL, with annual rainfall to 18 to 60 inches. It is associated with Lualualei and Ewa soil, and consists of stones and boulders covering 15 to 90 percent of the surface. Soil collecting between the stones is usually enough to provide a foothold for plants, consisting of reddish silty clay loam similar to Ewa soils, and of very dark grayish-brown clay similar to Lualualei soils. Stony Land is used for wildlife habitat and recreation, and includes natural vegetation such as kiawe, lantana, koa haole, bermudagrass, and annuals.

The following soils, while not mapped along the road alignment above the Dent St. terminus, have been identified as being associated with the Stony Land found at the alignment from the Dent St. terminus to the proposed portal.

#### EwC Ewa Stony Silty Clay

Ewa series are well-drained soils in basins & alluvial fans on Maui and Oahu, developed from basic igneous rock on low to moderate slopes from elevations near sea level to 150 feet. Annual rainfall is 10-30 inches, most falling between November and April. Ewa soils are used for sugarcane, truck crops, and pasture. Natural vegetation is fingergrass, kiawe, koa haole, klu, and hualoa.

EwC (stony silty clay) is similar to Ewa Silty Clay Loam, except for the texture of the surface layer. A detailed representative profile of Ewa Silty Clay Loam is attached. The surface layer is dark reddish-brown silty clay loam about 18 inches thick (containing stones in the case of EwC), overlying subsoil that is about 42 inches thick, dark reddish-brown and dark-red silty clay loam having subangular blocky structure. Substratum is coral limestone, sand, or gravelly alluvium. For the Ewa series in general, permeability is moderate; available water capacity is about 1.3 inches/foot (surface layer) and 1.4 inches/ft (subsoil). This soil is more than 60 inches

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deep, and in some areas roots penetrate to a depth of 5 feet or more. EwC has slow to medium runoff, slight to moderate erosion hazard, and includes small, gently sloping areas.

#### LvB Lualualei Stony Clay

Lualualei series soils are well-drained soils developed in alluvium and colluvium and occurring on level to gently sloping coastal plains, alluvial fans, and talus slopes of Kauai, Oahu, Molokai, and Lanai. Included in LvB mapping are small, steeper areas (from 6 to 12 percent slope). Elevations range from 10 to 125 feet, and annual rainfall is 18 to 30 inches, but ranges from as low as 10 inches on Lanai to as high as 50 inches on Kauai, mostly in the stormy period from November to April. There is usually a prolonged summer dry period. These soils are geographically associated with Honouliuli, Jaucas, and Kekaha soils. They are used for agricultural purposes, wildlife habitat, urban development, and military installations, and have natural vegetation consisting of kiawe, koa haole, bristly foxtail, uhaloa, and fingergrass.

The surface layer is about 10 inches thick, dark grayish-brown, very sticky and very plastic clay with prismatic structure. LvB is similar, but is stony, enough to hinder machine cultivation. It overlies subsoil that is 37 to more than 42 inches thick clay similar to surface clay, except that it contains gypsum crystals. The substratum is coral, gravel, sand, or clay at depths below 40 inches. The soil cracks widely upon drying. Permeability is slow, runoff is slow, and erosion hazard is slight. Available water capacity is about 1.4 inches per foot of soil. Shrink-swell potential is high. In places roots penetrate to five feet or more of depth.

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### **PRELIMINARY ROADWAY GRADING AND STABILITY REQUIREMENTS**

The soils on the Kunia side of the tunnel approach roadway are generally expected to be stable and reusable as fill, if free of debris and oversized particles. Slopes of 2 horizontal to 1 vertical can be planned for cut and fill slopes. Steeper slopes may be possible based on a geotechnical investigation or review by a soils engineer. The soils, especially at the lower approaches, have generally low CBR (California Bearing Ratio) values which affect pavement design (see next section).

The soils on the Lualualei side are generally stony land consisting of boulders and stones mixed with Ewa and Lualualei series soils. Most of the soils are generally stable, with the exception of the Lualualei series soils which are highly expansive and subject to downslope creep movements.

We anticipate that most soils will either contain expansive soils or oversized particles which will make reuse as fill difficult. Slopes of 2 horizontal to 1 vertical can be planned for cut and fill slopes. Where slope areas are identified by reconnaissance or geotechnical investigation as primarily consisting of expansive soils, shallower cut and fill slopes may be necessary. While we anticipate that most areas of the proposed approach roadway will contain only limited quantities of expansive soils and will not require any special stabilization measures (other than increased pavement thicknesses as described in the following section) a geotechnical investigation or review by a soils engineer is required to identify areas which may require stabilization measures due to the presence of expansive soils which may result in downslope creep movements.

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### **PRELIMINARY ASSESSMENT OF ROADWAY PAVEMENT REQUIREMENTS**

We anticipate that soils on the Kunia side roadway alignment will have low CBR values, generally less than 10. Although traffic information is not available, we anticipate that a typical pavement cross section will consist of 3 inches of AC over 6 inches of basecourse over 12 inches of select borrow subbase.

For the Lualualei side of the roadway alignment, we anticipate that subgrade soils will be highly variable ranging from surface rock exposures to near surface residual (Ewa series soils) and expansive (Lualualei series) soils.

For expansive Lualualei soil subgrades, we anticipate that the a typical required pavement section will consist of 3 inches of AC over 6 inches of basecourse over 24 inches of select borrow. For Ewa series soils, we anticipate a pavement section similar to the Kunia side roadways. For pavements which will directly overlie basaltic rock or rock like soil, we anticipate that the 3 inches of AC and 6 inches of basecourse can be placed directly on the rock.

For most of the tunnel, we anticipate that the subgrade will consist of rock. A short section at the Kunia Portal will likely require a pavement section similar to the Kunia approach roadway.

We recommend that final pavement designs be based on a detailed evaluation of the anticipated traffic, design life, and field and laboratory investigations of soil types and characteristics.

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### CONCEPTUAL TUNNEL DESIGN AND COST ESTIMATES

A conceptual tunnel design was developed by Jacobs Associates, based on parameters provided as outlined in this report. Tunnel features include a total interior width of 29 feet to accommodate a 24 foot roadway and safety walkways, and a total interior height of 24 feet to accommodate a ventilation system. The tunnel lining would be 14 inch cast in place concrete.

Please refer to the Jacobs Associates report, Attachment 1, for conceptual tunnel design details.

As the study was being completed, a request was made to provide a breakdown of costs for elements of the tunnel so that other tunnel lengths could be considered. Considering the conceptual nature of this study, providing more detailed cost estimates was considered to place undue emphasis on the precision of the cost estimates. Rather, Jacobs Associates has provided the following estimates based on their best judgment as to the costs for tunnels of different lengths:

One Mile Tunnel:                      \$99 million (bi-directional) / \$130 million (uni-directional)

Half-Mile Tunnel:                      \$59 million / \$91 million  
(Tunnel civil and structural work at half cost + 20%, all systems at half of 1-mile tunnel costs.)

800-Foot Long Tunnel:                \$18 million / \$24 million

[Tunnel civil and structural work at proportionately less (800/5200) + 20%, no cost for ventilation or TMS, proportionately less (800/5200) for ventilation and finish]

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### FURTHER INVESTIGATIONS

In order to develop more definitive design scenarios and cost estimates, the following further investigations are recommended as the next step in the planning process. More detailed descriptions of items 1 through 3 are presented in the Jacobs Associates report, Attachment 1.

#### 1. Analysis of anticipated tunnel use and safe operation

This would be a combination of traffic engineering and tunnel operations studies conducted as a joint effort of owner and engineer to establish a basis for tunnel operation.

#### 2. Alternative tunnel configurations and roadway layout

Based on item 1, several tunnel configurations could be studied. The duration of a study for items 1 and 2 could range on the order of 3 to 6 months. More tunnel engineering would be required in order to perform a more detailed cost estimate. It is assumed that at this stage of the project, no additional geotechnical information (i.e. drilling data) would be available.

Cost estimates to perform items 1 and 2 and to perform at least two detailed cost estimates are on the order of \$125,000.

#### 3. Tunnel ventilation studies

Ventilation requirements are a major factor in tunneling costs for longer tunnels. For select scenarios from items 1 and 2, the estimate of costs for the studies for two ventilation alternatives is on the order of \$35,000 including a report and equipment layouts.

#### 4. Geologic conditions

The recommended scope of further investigation includes a detailed geological reconnaissance and subsurface exploration at the portals, followed by additional investigation based on the results. A detailed geological reconnaissance could likely be conducted for approximately \$35,000. Because of difficult access likely requiring helicopter setups and specialized drilling requirements, the cost of the exploratory drilling and lab testing program at the portals would likely be on the order of \$150,000 to \$250,000 depending upon the scope of exploration. Because of the high cost of field explorations, we recommend that a detailed geological reconnaissance be conducted in conjunction with detailed tunnel and ventilation studies and a tunnel alignment with tunnel portal locations identified prior to mobilization for drilling at portal locations.

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### LIMITATIONS

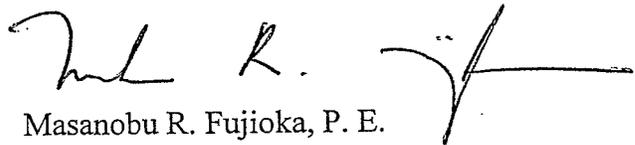
We have prepared this geotechnical engineering letter report for preliminary planning purposes, in accordance with generally accepted soils and foundation engineering practices. No other warranty, expressed or implied, is made as to the professional advice included in this report. This report may not contain sufficient information for the purposes of other parties or for other uses.

- o o o -

It has been our pleasure to prepare this letter report for you. Please contact the undersigned if there are any questions regarding this letter report.

Respectfully submitted,

MASA FUJIOKA & ASSOCIATES  
A Professional Partnership



Masanobu R. Fujioka, P. E.  
Principal-In-Charge

MRF

(two copies submitted)

Attachments:

Figure 1, Map of Area

Figure 2, Soils Map

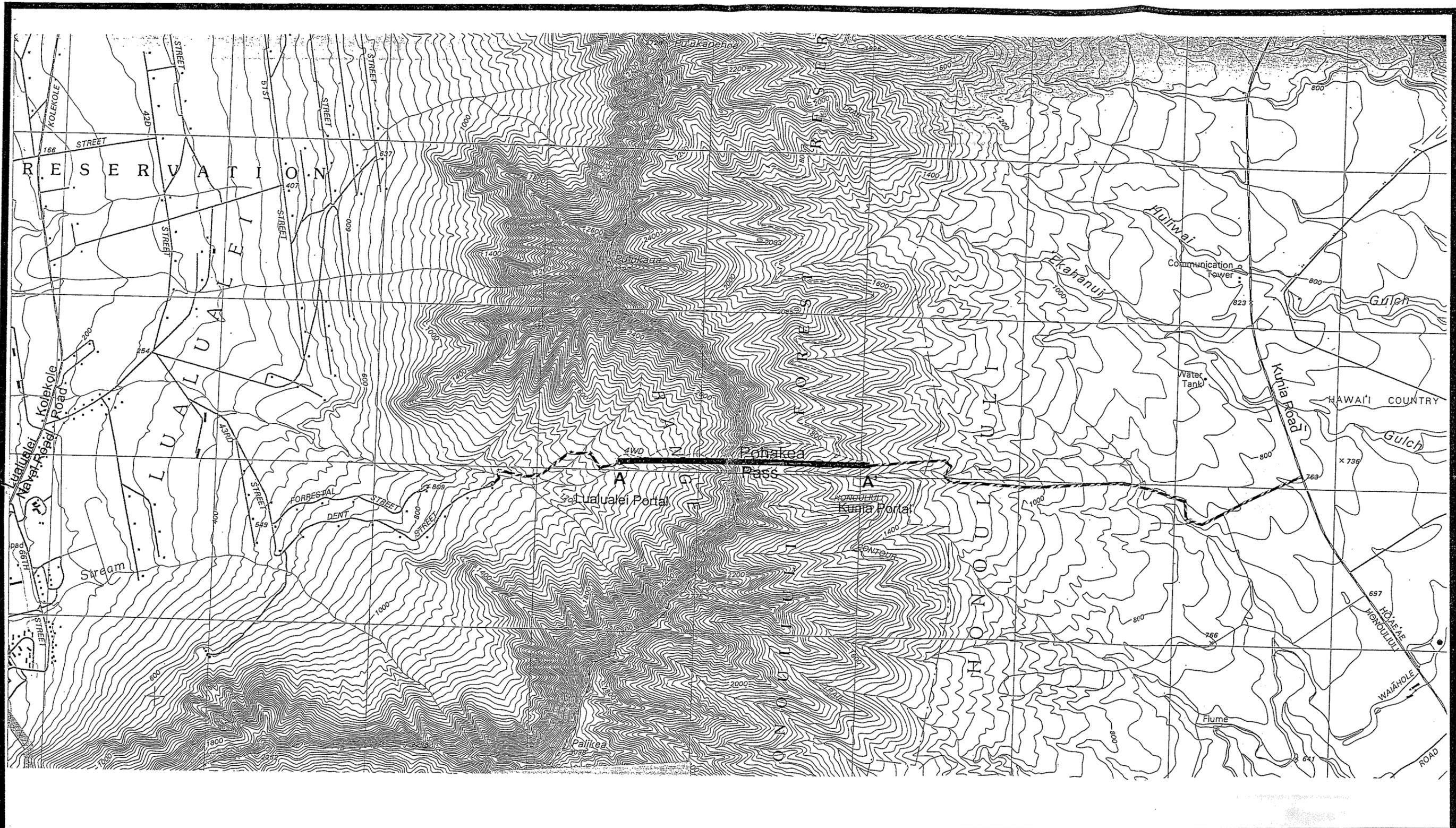
Figure 3, Geologic Cross Section

Attachment 1, Jacobs Associates Report

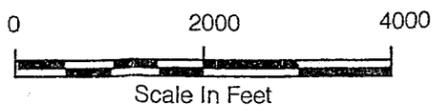
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**FIGURES**



- Legend:
-  Proposed Tunnel Access Roads
  -  Proposed Tunnel Alignment

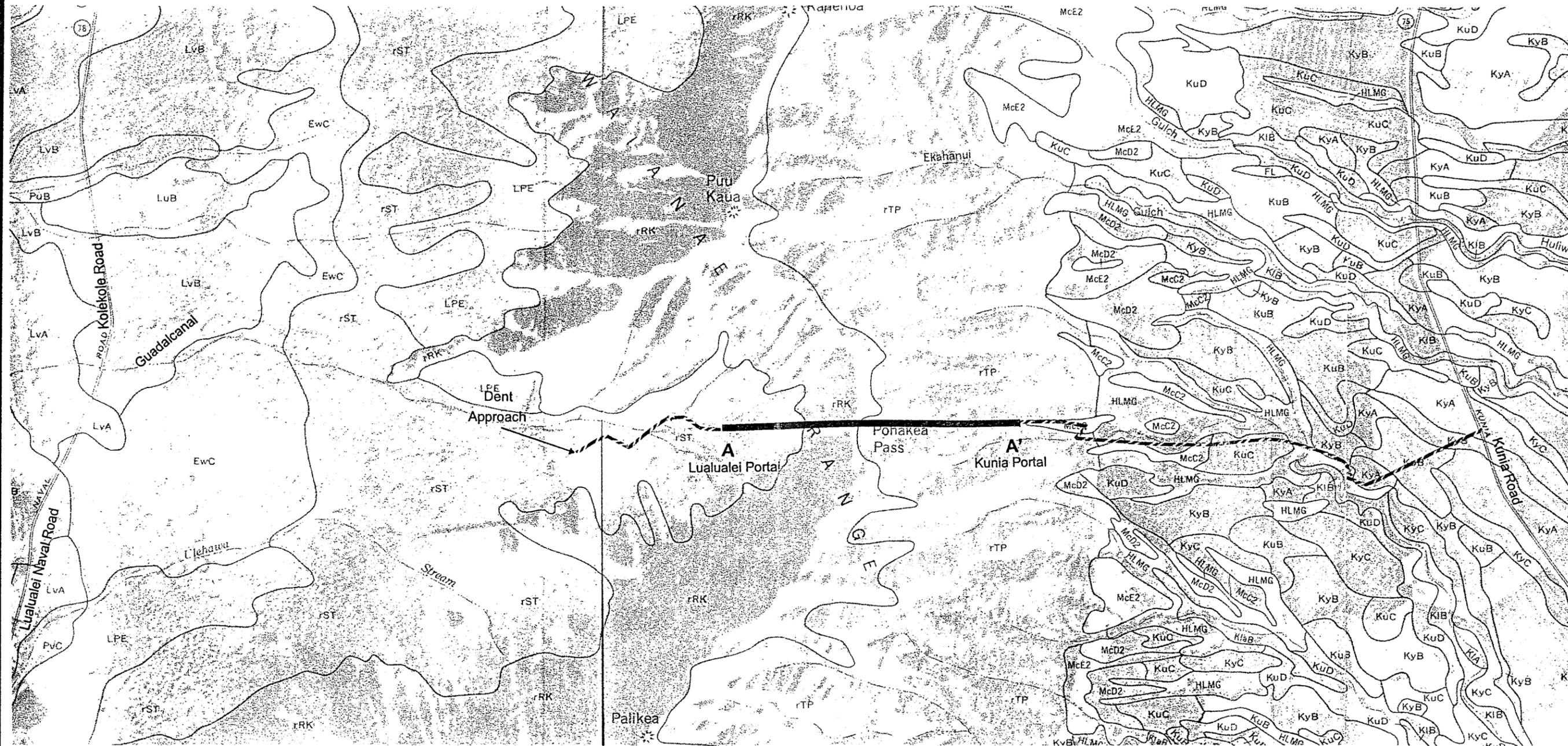


Site Plan Source: USGS Scholfield Barracks Quadrangle (1998)

Project No.	01151-005
Drawing No.	01
Approved By:	MRF
Drawn By:	SFGS
Rev:	1
Date:	7/10/01
Scale:	1" = 2000'

**Figure 1**  
**Map of Area**  
 Proposed Waianae Tunnel  
 Pohakea Pass, Oahu, Hawaii

**M<sub>F</sub>A** MASA FUJIOKA & ASSOCIATES  
 ENVIRONMENTAL • GEOTECHNICAL • HYDROGEOLOGICAL CONSULTANTS



Legend:

 Proposed Tunnel Access Roads

 Proposed Tunnel Alignment



0 2000 4000



Scale In Feet

Site Plan Source: Foote, et al., 1972

Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii

Project No. 01151-005

Drawing No. 01

Approved By: MRF

Drawn By: SFGS

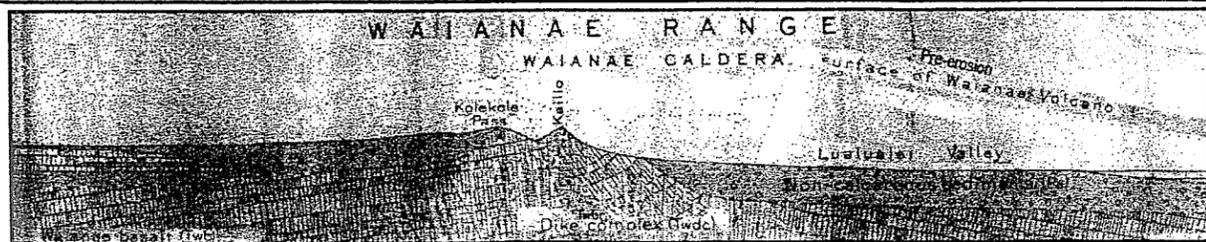
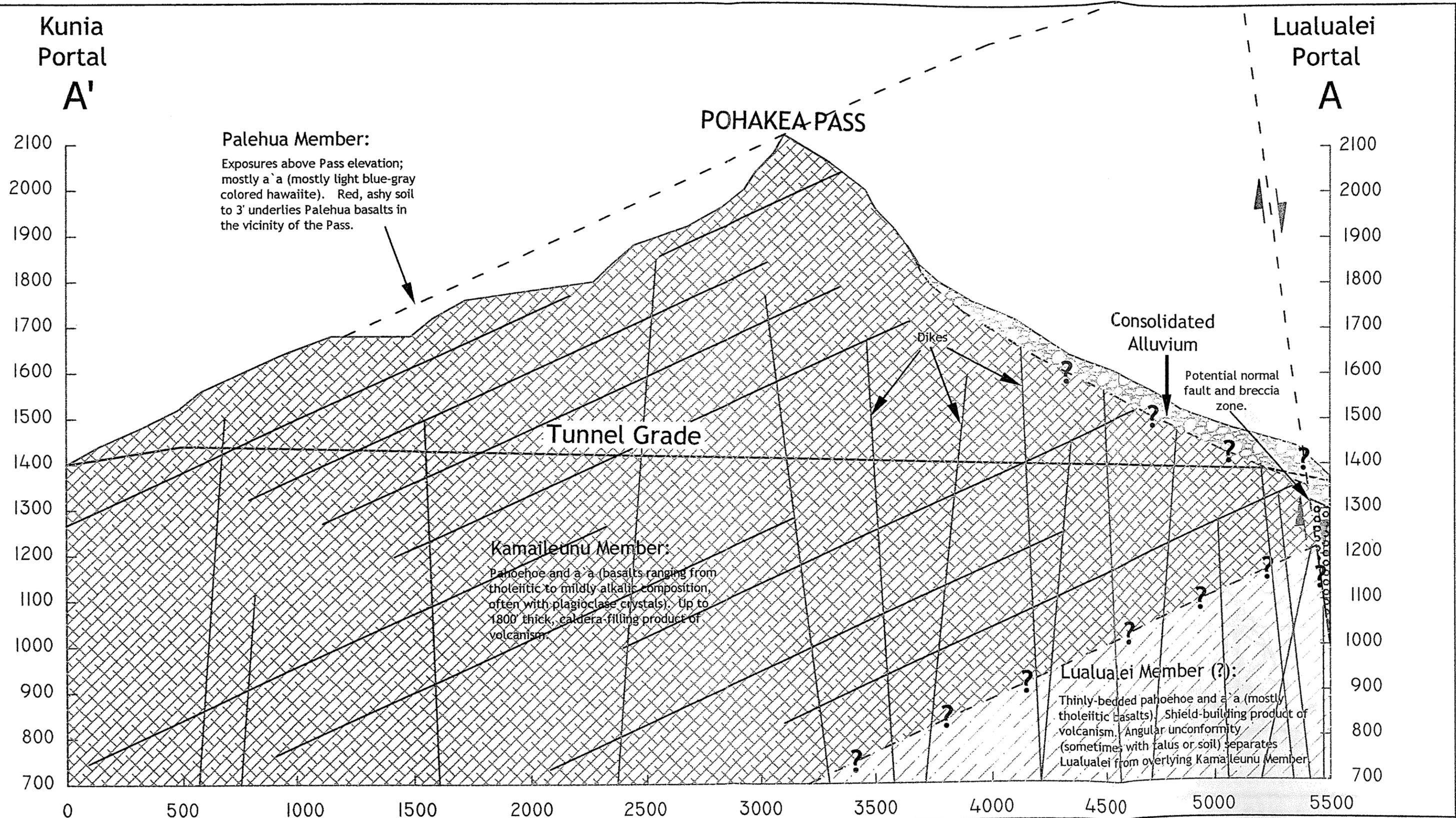
Rev: 1

Date: 7/10/01

Scale: 1" = 2000'

**Figure 2**  
**Soils Map**  
Proposed Waianae Tunnel  
Pohakea Pass, Oahu, Hawaii

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INSET: Geologic cross-section at Kolekole Pass (Stearns, 1938) north of Pohakea Pass.

Horizontal and vertical scales are in feet.  
Vertical exaggeration is two times horizontal scale.

Dike locations are not definitively mapped at present; however, dikes are assumed to increase in number towards the caldera zone, as pictured.

Source: Elevations from USGS Schofield Barracks Quadrangle Topographic Map (1998)

Project No.	01151-005
Approved By:	MRF
Drawn By:	BATS
Date:	7-10-01
Scale:	1"=500' (Horizontal)

**Figure 3**  
Geologic Cross Section  
Proposed Waianae Tunnel  
Pohakea Pass, Oahu, Hawaii

**MFA** Masa Fujioka & Associates  
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**APPENDIX B**

**CONCEPTUAL STUDY, WAIANAE TUNNEL  
HONOLULU, HAWAII**

**For**

**LUALUALEI NAVAL ROAD/KUNIA ROAD CONNECTOR  
CONCEPT STUDY**

**Prepared By**

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## **Conceptual Study, Waianae Tunnel**

**Honolulu, Hawaii**

### **for Lualualei Naval Road/Kunia Road Connector Concept Study**

**28 August 2001**

Conceptual design, construction costs, and issues for further evaluation for a highway tunnel in the Waianae Range of mountains on Oahu, Hawaii are presented in this report. The intention is that this effort support the evaluation of roadway alternatives for a broader study being undertaken.

Jacobs Associates (JA) of San Francisco, California was engaged by Masa Fujioka & Associates (MF&A) for this tunnel study. MF&A is the geotechnical subconsultant to Gray, Hong, Bills, Nojima and Associates, Inc (GHBN) who are conducting the Concept Study on behalf of the City and County of Honolulu Department of Transportation Services. Given the concern for tunnel ventilation and safe tunnel operation, JA engaged Earth Tech (ET) of Oakland, California for specific advice on ventilation systems, which has been incorporated herein. The overall study is called the "Lualualei Naval Road/Kunia Road Connector Concept Study" and the tunnel portion is referred to herein for convenience as the "Waianae Tunnel."

#### **Summary**

A tunnel of about one mile long with bi-directional traffic is being considered as a part of an alternate emergency access road from the Waianae side of Oahu (Leeward Coast) instead of the sometimes congested or closed coastal roadway. The main concern for a tunnel of this length and contemplated bi-directional use is safe operation.

The tunnel being considered is quite different than the existing roadway tunnels in Hawaii. Oahu has three highway tunnels of significant size (see Figure 1): Pali Tunnel (a pair of fairly short tunnels, without mechanical ventilation), Wilson Tunnel (a pair of tunnels about one-half-mile long with a semi-transverse ventilation system), and Interstate Highway H-3/Tetsuo Harano Tunnel (a pair of tunnels designed with Interstate Highway standards and a full-transverse ventilation system). All of these tunnels carry uni-directional traffic, except in special, limited maintenance or emergency situations where operation is bi-directional.

The tunnel study first considered a typical two-lane tunnel with geometry similar to that of the existing Pali Tunnel (see Figure 2). That configuration puts the un-divided, two-lane, bi-directional open roadway in a tunnel with lighting and a longitudinal ventilation system. The major issues involve greater risks and consequences of accidents in the confinement of the tunnel, particularly with a fire. The conclusion was that it would not be practical to safely remove traffic and evacuate the tunnel for an accident involving a fire, even with a modern ventilation system. Consequently, another tunnel scheme was considered.

To change the two-lane uni-directional tunnel (Figure 2) into a bi-directional operating tunnel (Figure 3), two key features were incorporated: a pair of center barriers that prevent head-on vehicular collision and provide a protected walkway for egress by people in emergencies, and a semi-transverse ventilation system with single-point extraction capability to control smoke in a fire. This is regarded as a feasible tunnel in concept. Design details are not standard and should not be considered as definitive nor comprising the only tunnel features that might ultimately be acceptable after further engineering studies. Construction cost for this two-lane, one-mile long tunnel is estimated to be about \$99 million with the contingencies as documented.

For a tunnel of half the present length being considered (for a tunnel of one-half mile length), a ventilation system would be needed and similar safety concerns would need to be addressed. The tunnel length would have to be 800 feet or less to significantly reduce concerns for acceptable, safe operation and to consider not having a ventilation system (as per current NFPA standards). What is considered 'acceptable' should be evaluated by practices in the United States and other countries world-wide that are setting precedents for tunnel design and safe operation, the entity responsible for highway operations, and the fire and police units or departments that have jurisdiction.

Recommendations are made if further consideration of a tunnel is made. In general order of importance and priority, they involve studies of traffic and operational scenarios including a comprehensive assessment of issues for achieving safe operation, broader study of the options for the use of tunnels for alternative roadway layouts and tunnel cross-sections, and investigation of geologic conditions.

## Conceptual Tunnel Design

### General Tunnel Considerations and Typical Cross-Section

Guidelines were given to JA through MF&A were that a "Pali-style" tunnel was envisioned, rather than a much larger Interstate Route H-3 (H-3) Tetsuo Harano Tunnel that was opened for traffic in 1997. The Pali Tunnel is a group of tunnels on the highway that traverses the Pali between Kailua and Honolulu. The Pali tunnels carry traffic uni-directionally, are short compared to the other highway tunnels (Wilson Tunnel and Harano), and rely on natural ventilation. The Pali and Wilson tunnels were constructed in the 1950's or early 1960's. Figure 1, developed for other work in 1989, gives the key dimensions of the existing tunnels. All of these tunnels are operated at typical highway speeds with commuter traffic.

JA was tasked to limit study of the proposed Waianae Tunnel to a single two-lane tunnel with bi-directional (two-way) traffic. Design speed would be 45 miles/hour with a posted limit of 35 miles/hour. Grades on the approach roadway could be relatively steep (12 percent maximum), but the tunnel would be limited to a maximum grade of 5 percent (tunnel profiles indicate a 2 percent grade). The ostensible purpose of the tunnel is an emergency alternative to other roadways. However, once opened for unrestricted use, the highway and tunnel could reasonably be expected to have a traffic volume at some time that could be near the practical hourly vehicle capacity. Occasional use could not be used as a basis for conceptual design, and the peak conditions would control the conceptual features.

The tunnel study evolved with first considering use of a typical two-lane uni-directional tunnel (Figure 2) in a bi-directional operating mode. After finding that concept unacceptable, other tunnel features were added to achieve a feasible bi-directional tunnel scheme (Figure 3).

### Simple Two-Lane Tunnel Configuration

Figure 2 presents the key dimensions and features assumed as a conceptual layout of a simple two-lane, uni-directional tunnel. The following elaborates on several of the assumptions and the concerns for use of this concept in a bi-directional traffic mode.

Roadway Width: Two 12-foot lanes match the existing Pali Tunnels. Total width finished is 29 feet. Sidewalks are shown and match other Oahu highway tunnel configurations. Major concerns for bi-directional operation are the risks of head-on collisions that have greater consequences in the confined tunnel conditions, particularly with a fire. There are essentially no shoulders and any vehicle accident or breakdown can effectively block the entire tunnel in both directions. Safe egress of people and emergency response with or without a fire would not be acceptable for a tunnel of the length being considered.

Tunnel Height: Maximum vehicle height of 16 foot 6 inches was assumed, which is the typical design height for U. S highway tunnels, although it is understood to be higher than the legal height for vehicles on Hawaii State Highways. Above the

vehicle envelope, an allowance has been made for ventilation, which is shown in Figure 2 as longitudinal ventilation fans, which could be as large as 5 feet in diameter. Also above the vehicle clearance would be any signage (fixed, variable, changeable message, lane use, or other); any closed circuit television cameras (CCTV); and other systems-related items. In general, it is considered desirable to have a liberal height for ventilation and signage and avoid a height restriction that might undesirably limit the usefulness of the tunnel. The incremental cost of adding slightly more height is not significant and is substantially less than costs for increasing tunnel width, as discussed below.

Tunnel Shape: A traditional “horseshoe” shape of the tunnel (circular arch, vertical sidewalls) was assumed.

Tunnel Lining: Cast-in-place concrete final lining with a PVC membrane waterproofing placed in the arch and sidewalls and terminating at the roadway. The membrane is essential to maintain a dry roadway. A finish on the sidewall of the tunnel has been assumed, with the intent of providing a maintainable (cleanable) surface that provides better distribution of the lighting and gives a brighter-appearing tunnel to the user, in comparison to bare or even painted concrete. Several options exist for materials.

The conclusion was that simply converting a uni-directional, two-lane tunnel to bi-directional operation was not acceptable. Consequently, another tunnel scheme was considered.

#### Two-Lane, Bi-Directional Tunnel

To change the two-lane uni-directional tunnel (Figure 2) into a bi-directional operating tunnel (Figure 3), two key features were incorporated as follows. The first feature is a pair of center barriers that prevent head-on vehicular collision and provide a protected walkway for egress by people in emergencies. The arrangement with a center walkway is not common; bi-directional roadways typically have a ‘walkway’ on each side of the tunnel, but each walkway therefore increases the tunnel width approximately 10 percent, thereby raising construction costs proportionally. The single walkway addresses the concern for safe personnel egress in an emergency by providing a path of escape not likely to be blocked by stalled vehicles and protected from traffic. The second feature is a semi-transverse ventilation system with single-point extraction capability to control smoke in a fire (see later discussion of ventilation). The features incorporated in this concept are intended to meet the broad objectives as stated by the NFPA being that “... the desired goal [is] to provide an evacuation path for motorists who are exiting from the tunnel and to facilitate fire-fighting operations.”

With these two significant features, the overall tunnel geometry was necessarily changed. The tunnel was widened with slightly wider traffic lanes of 14 feet. In order to minimize tunnel width, there is no shoulder. Addition of breakdown bays (a local widening of the tunnel to permit stalled vehicles to be stored and traffic maintained) were considered, but

were in the end not incorporated and were considered to be too complex to consider at this stage of the study. The ventilation system requires a ceiling and portioned plenums, which requires some additional height. Finally in order to have a tunnel that could be constructed efficiently, a rounded shape was adopted as shown in Figure 3. A straight-legged, vertical sidewall tunnel configuration would have been unnecessarily large, and from a geotechnical and structural aspect, the curved shape in Figure 3 is considered more desirable.

### Geology and Geologic Conditions

No site-specific geologic investigation by borings was performed, nor was a walk of the projected portal locations or general tunnel line undertaken. The regional geology from published documents (MacDonald et al 1983, Stearns 1985) and draft versions of the geotechnical report, including an early draft section entitled "Pohakea Pass-Geology" (MFA#01151-005) were reviewed to establish the general geologic character of the tunnel alignment. The tunnel is in the Waianae Range, which is the erosional remnant of the long-extinct volcano. Inherent with volcanic rocks in this geologic setting is intrusion of molten material into the older lava flows that form dikes in an pattern. Other complex geologic structures can result from faulting and successive cycles of erosion and lava flows. All of these features would have relevance to tunneling. In general it is possible to construct a tunnel in such geologic conditions if the range of geologic conditions is reasonably understood before construction starts and adequate plans are made to deal with changing conditions as the work progresses.

Based on the information available, the tunnel would be constructed in volcanic rock (interlayered flows of pahoehoe and a 'a) dipping about 25° to the east toward the Schofield/Kunia portal. It was assumed that no major fault or major zone of shearing exist (of possibly 100s of feet in extent) that would require extraordinary construction methods. Dikes of up to 3 feet in thickness, nearly vertical, and oriented generally perpendicular to the tunnel line would be expected. Rock quality (weathering and jointing) was assumed to vary along the tunnel line. The Lualualei Portal was indicated to have consolidated alluvium (assumed to be like a stiff soil) and a breccia zone (broken rock) of unknown thickness. This condition could be very significant to the start of tunneling. The Schofield/Kunia Portal was indicated to have some weathering but overall was indicated to be of less significance to tunneling. Neither the portals nor any zone along the tunnel would have extensive zones of weathering, such that the rock would be weathered to a soil-like saprolite (like for limited length of the Halawa Portal of the H-3 Harano Tunnel), or even more weathered to a residual soil that was present in the Kalihi Valley (Honolulu side) of the Wilson tunnel. An allowance was made in the cost estimate, however, for some poor ground conditions along the tunnel as well as for more ground support at the start of tunneling.

### Tunnel Construction

Methods: This tunnel is assumed to be excavated by drill and blast methods in volcanic rocks utilizing top heading and bench procedures over the full length. Some reaches of the tunnel may require smaller working faces to advance the top heading in three parts

consisting of a center tunnel heading and sidewall headings. Where poor ground conditions exist, such as possibly at the Lualualei Portal, special procedures and sequence would have to be used (sequential excavation methods). The curved shape in Figure 3 is desirable in poor geologic conditions but would not penalize construction in better rock conditions.

Initial Tunnel Support: Assumed rock reinforcement is shotcrete. This was used successfully for all of the H-3 tunnel construction and follows continuing industry trends for using rock reinforcement rather than structural steel. It has been assumed that rock reinforcement would be of the friction-type (Swellex<sup>®</sup>), although fully grouted resin- or cement-grouted rock dowels could be used. More precise definition of ground support is not justified in view of the limited knowledge of the geologic conditions and the conceptual nature of the study.

### Tunnel Ventilation<sup>1</sup>

General Ventilation Requirements: Due to length of the tunnel, ventilation is necessary during normal operations and during a tunnel fire emergency. Ventilation during normal operations is necessary to limit the concentration of contaminants produced by vehicle engines to acceptable levels. Ventilation during fire emergency is necessary to remove and to control smoke and hot gases due to fire, and to assist in the evacuation of motorists/passengers. Ventilation requirements are assumed to meet standards of the National Fire Protection Association (NFPA), Standard 502, "Road Tunnels, Bridges and Other Limited Access Highways." Highway tunnels in the United States generally follow this standard, which has been updated as recently as 1998 and is likely to be updated in the near future as other technologies and worldwide experience are being brought into US practice. A recent publication by ASCE (Bendelius, 2001) illustrates the on-going global efforts to achieve safer roadway tunnels, particularly with regard to fire life safety.

Normal operation: Motor vehicle engines produce emissions of carbon monoxide (CO), oxides of nitrogen (NO<sub>x</sub>) and hydrocarbons. Sufficient airflow quantities are required to maintain concentration of these contaminants to acceptable levels. ASHRAE (American Society of Heating, Air Conditioning and Refrigerating Engineers) recommends that medical authorities should be consulted for acceptable CO concentrations for tunnels more than 5000 feet long. This would be particularly of concern for tunnels at great elevation, but not of particular concern for tunnel in this study.

The airflow may be produced by the piston effect of the motor vehicles or by mechanical ventilation. The airflow generated by natural ventilation relies on winds, tunnel grade, ambient temperatures, and direction of the traffic. Given its length and bi-directional traffic in the Waianae tunnel, it is anticipated that piston effect would not generate necessary airflows to maintain acceptable concentration levels. A computer simulation would be required to verify this assumption. Trade winds in Hawaii may also be a

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<sup>1</sup> The Tunnel Ventilation section of this report was provided by Earth Tech of Oakland, California. The staff of Earth Tech with expertise in tunnel ventilation were previously known as Kaiser Engineers.

significant consideration. Given the apparent conditions, it is therefore anticipated that some kind of mechanical ventilation will be necessary during normal operations.

Emergency operations (Fire): According to NFPA Standard 502, since the tunnel is more than 800 feet long, ventilation will be required during emergency operations for smoke control. Emergency operations generally result when one or more vehicles are disabled and particularly on fire. Such emergency requires evacuation of motorists. For such conditions the tunnel emergency ventilation system must be able to maintain a single evacuation path from the fire location, clear of smoke and hot gases, providing for safety of motorists. The safe evacuation path is maintained by providing airflow in the desired direction and by maintaining airflow velocity at or above 'critical velocity'. Critical velocity is the value at which backlayering of smoke and hot gases does not occur. Backlayering is the movement of smoke and hot gases contrary to the direction of the ventilation airflow in the tunnel.

The design of the tunnel ventilation system needs to take into account the potential for a major fire to occur at any location in the tunnel. The type of motor vehicles used in the tunnel system determines the largest fire that can occur. A maximum Heat Release Rate (HRR) for the fire is determined taking into consideration all types of vehicles that will be used in the tunnel.

When a fire occurs in a tunnel appropriate fans must immediately be activated to control the smoke and heat, and the air movement must ensure a safe evacuation route. Emergency scenarios consist of modeling a vehicle on fire in the steepest tunnel section and ventilating against buoyancy (down hill) in order to design the fans to the largest duties (the worst-case scenario).

Computer simulation of emergency ventilation is required to determine the predicted airflow past the fire and to compare it with the "critical velocity" value calculated for that particular fire location. The aim is to demonstrate that a flow above the critical value can be maintained in order to prevent the backlayering of the smoke and fumes along the evacuation routes. The emergency ventilation system is required also to meet the following conditions:

- Airflow at or above calculated critical velocity and in the desired direction for fire location and HRR.
- Air temperature in the evacuation path shall not exceed 60°C (140°F)
- Air temperature through emergency fans and equipment should not exceed 250°C (482°F) for one hour.

### Ventilation Systems

Substantial analysis including numerical modeling would be required to determine the ventilation requirements during normal and emergency operations and the adequacy of natural ventilation. As background on the range of systems, the following ventilation systems can be considered.

Longitudinal Ventilation – Longitudinal ventilation is achieved by jet fans installed at certain intervals throughout the length of the tunnel, or directional air injection at one of the portals. Air injection requires a fan shaft at the portal. Application of jet fans for this project would require a rigorous traffic control to restrict the access of vehicles in case of a fire. Further, more detailed analysis is necessary to verify the applicability of jet fans for this project, including computer modeling.

Longitudinal ventilation can also be achieved by an exhaust fan shaft at a mid tunnel location. While longitudinal ventilation is the most cost-effective for unidirectional traffic, it may not be effective for the Waianae tunnel because of bi-directional traffic, unless the traffic is very light. This type of ventilation system has extensive use outside the United States, but is increasingly being considered for use in the US as the standards are updated and the efficacy of the system is tested.

Semi-Transverse Ventilation – Semi-transverse ventilation can be configured as either 'supply' or 'exhaust' ventilation by providing either supply or exhaust fans and a distribution ductwork throughout the length of the tunnel. For a supply air system, the exhaust is through the portals, and for an exhaust air system the supply is from the portals.

For bi-directional traffic tunnel, a supply type system produces uniform contaminant levels throughout the tunnel. For normal operation the supply air should be provided at a low level of the tunnel height to dilute the vehicle engine emissions. In case of semi-transverse system for normal and emergency operations, a reversible fan should be provided with supply air outlets at ceiling or at higher level. During normal operation the fan operates in the supply mode. During emergency operations the fan operates in the exhaust mode and smoke and hot gases are picked up at higher level and supply is from portals.

The Wilson Tunnel on Oahu has an exhaust type of semi-transverse ventilation system with exhaust through ceiling ducts into the plenum and finally exhausting through non-reversible fans from the fan building near the Kalihi portal.

Full-Transverse Ventilation – Full-transverse ventilation system is similar to a semi-transverse system, but includes both supply and exhaust fans and associated distribution ductwork. Full-transverse ventilation systems are used for long tunnels and heavy traffic. The H-3/Harano Tunnel has a full-transverse ventilation system.

Single Point Extraction – In concept, it is desirable to remove the smoke from a fire at the source. With a single point extraction system, the ceiling has a damper, a relatively large area with louvers, that can be opened automatically (or by a manual control) at or near the fire. Fans running at maximum capacity would

operate to exhaust the smoke into the dedicated ceiling exhaust duct. This system intends to keep smoke away from the people in the tunnel in the most efficient way possible at or near the source.

For the conceptual study, a semi-transverse ventilation system with the capability for single point extraction of smoke in a fire emergency was assumed. In Figure 3, the single point extraction exhaust duct is shown separate from the exhaust ducts for ventilation of normal tunnel traffic. Relative sizes and arrangement of ducts should be considered conceptual but gross size of the exhaust ducts relative to the traffic area of the tunnel is considered to be in line with past tunnel experience. A ventilation building would be required at one portal and would house ventilation fans and other related tunnel systems equipment.

### Lighting

Tunnel lighting would be required and can be of several types, such as fluorescent, high-pressure sodium, or low-pressure sodium. A typical practice is to use a luminaire (complete lighting unit) that is used for other tunnels in the locality so that lamps and other parts are the same and maintenance is simplified. An allowance was made for the lighting in the cost estimate, but no specific system was assumed.

### Traffic Management System, Signals, Signage

In the cost estimate, an allowance was made for 'tunnel systems' elements that are not part of lighting or ventilation. This would include CCTV cameras, lane use indicators, variable message signs, emergency telephones, and others items. The most elementary case would be for nothing. This is unlikely to be acceptable for a one-mile-long tunnel open to the public regardless of the expected level of service. Something would be required, and the specific needs could only be determined after a great many other tunnel operating conditions were established.

### Fire Protection

Prevailing standards to deal with the fire life safety risks in the tunnel require several features. They typically include manually operated fire alarms, automatic fire detection systems, standpipes for water supply for fire fighting, and a water supply.

## Cost Estimate

The foregoing parameters and assumptions provided the basis for developing conceptual-level construction cost estimates for each tunnel concept using a proprietary, in-house estimating program that utilizes methods- and production-based cost estimating algorithms. For comparison, the two-lane, uni-directional traffic tunnel costs are given as well as for the bi-directional tunnel.

	<b>Uni-Directional Tunnel</b>	<b>Bi-Directional Tunnel</b>
Tunnel and Portals: Civil and Structural	\$53,000,000	\$63,000,000
Tunnel: Systems	\$13,000,000	\$16,000,000
Subtotal	\$66,000,000	\$79,000,000
Contingency	\$16,500,000	\$20,000,000
<b>Total Construction Contracts, say</b>	<b>\$83,000,000</b>	<b>\$99,000,000</b>

**The total estimated amount represents the sum total of construction contract payments, and exclude design and construction management fees. The estimate anticipates a 3-year construction duration; therefore, costs have been indexed to August 2001 with provision for escalation. A contingency amount has been included, representing some 25 percent of estimated construction. This contingency represents uncertainties in project definition, geotechnical investigations, and estimating precision.**

## Issues for Further Study

### 1. Anticipated Tunnel Use and Safe Operations

Use of the tunnel, operational scenarios that are realistic, and the risks posed by accidents and fire in the tunnel should be studied further.

Projections should be made of traffic volumes for a number of scenarios. In such projections, the mix of vehicles (truck, automobiles, gas and diesel engine) should be made. Along with the traffic projections, evaluation should be made for a range of credible scenarios of the management of emergency situations, in particular response time for dealing with accidents in the tunnel, with and without a fire.

### 2. Alternative Tunnel Configurations and Roadway Layout

More than one tunnel configuration should be studied.

For many mountainous situations, a tunnel offers a major mitigation of environmental impacts of roadway construction and simplification of the roadway alignment. Broader alternatives could be considered:

- Adding refuge bays (local widening of the tunnel) that would permit temporary storage of a disabled vehicle after an accident
- Two smaller uni-directional tunnels
- Different tunnel cross-section with a single center barrier, but other safe means for egress as by fire-protected and ventilated refuge bays or a tunnel dedicated emergency pedestrian use
- Other ventilation schemes
- Limiting use of the single two-lane tunnel to one-way traffic
- Tunnel of substantially shorter length for different roadway layouts.

### 3. Tunnel Ventilation Studies

For any tunnel configuration and operational assumptions, further engineering studies are necessary to confirm the applicability of the ventilation system in compliance with the current standards. Computer modeling and simulation should be used and the following software is recommended:

SES – The Subway Environment Simulation (SES) computer program is a one-dimensional network model and can be used to examine longitudinal flow in the road tunnel. This software has the longest history of development and use, but cannot model the more complex phenomena associated with a tunnel fire.

TUNVEN – The program can predict quasi-steady-state longitudinal air velocities and the concentrations of CO, NO<sub>x</sub> and total hydrocarbons along a highway tunnel. The program can model all ventilation systems: longitudinal, semi-transverse and fully transverse.

SOLVENT – A computational tool for the simulation of fluid flow, heat transfer, and smoke transport in tunnels. The tunnel ventilation model, using a numerical method, solves the three-dimensional, time-dependent equations. This software is computationally intense and can model tunnel fires.

#### 4. Geologic Conditions

Site-specific geologic information should be obtained for any but the broadest consideration of a tunnel.

The present study is conceptual in nature and the assumed geologic conditions rely on regional geology and on past experience with tunneling on Oahu. The approach to getting more information should be in steps as follows:

- a. Geologic reconnaissance: this would be full review of the published information, possibly with the assistance of geologists or academics in Hawaii who may still be in practice that authored the original works. This effort would be accompanied by a field reconnaissance of the outcrops on the alignment and possibly use of air photos to learn as much as possible about the major structural features that might be relevant and detectable by this effort.
- b. Subsurface exploration at proposed portals: after a. above is completed, at least one, and possibly more, rock core borings should be drilled at the portals to determine the conditions. The emphasis should be on recovering core in a range of conditions, including near soil-like conditions. It is strongly recommended that the methods used at the Halawa Portal for the H-3 tunnels be used, which obtained near full recovery of the weathered rock, including saprolite, that would have not been achieved with traditional rock drilling practices. A laboratory testing program would accompany the drilling program.
- c. Additional Exploration: Depending on the depth to the tunnel, more borings might be warranted to further characterize the site. The need and plan to conduct should be done only after the items above are completed, and if warranted for the undated understanding of the geologic conditions and tunnel alignments that are in serious consideration.

## References

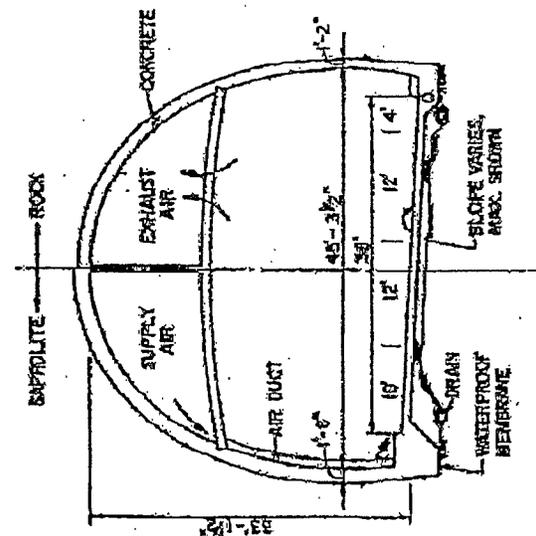
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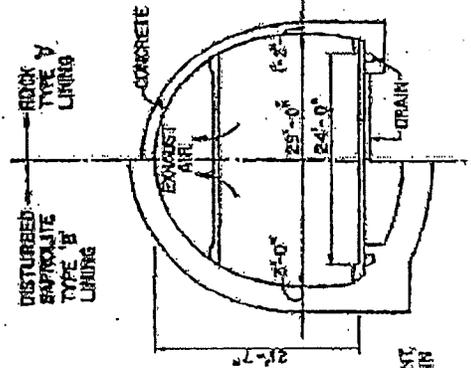
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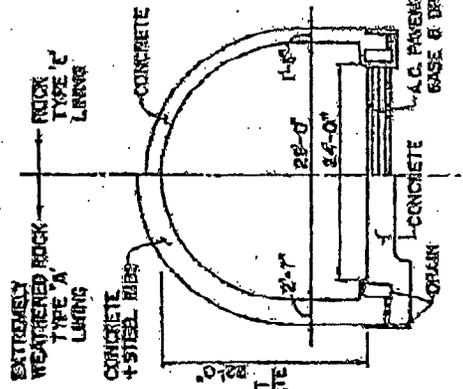
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JA Project No. 3703  
WHH



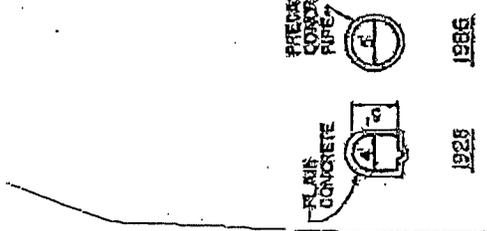
INTERSTATE H-3  
TRANS-KOOLAU  
TUNNEL



WILSON  
TUNNEL  
2ND BORE



PALI  
TUNNEL

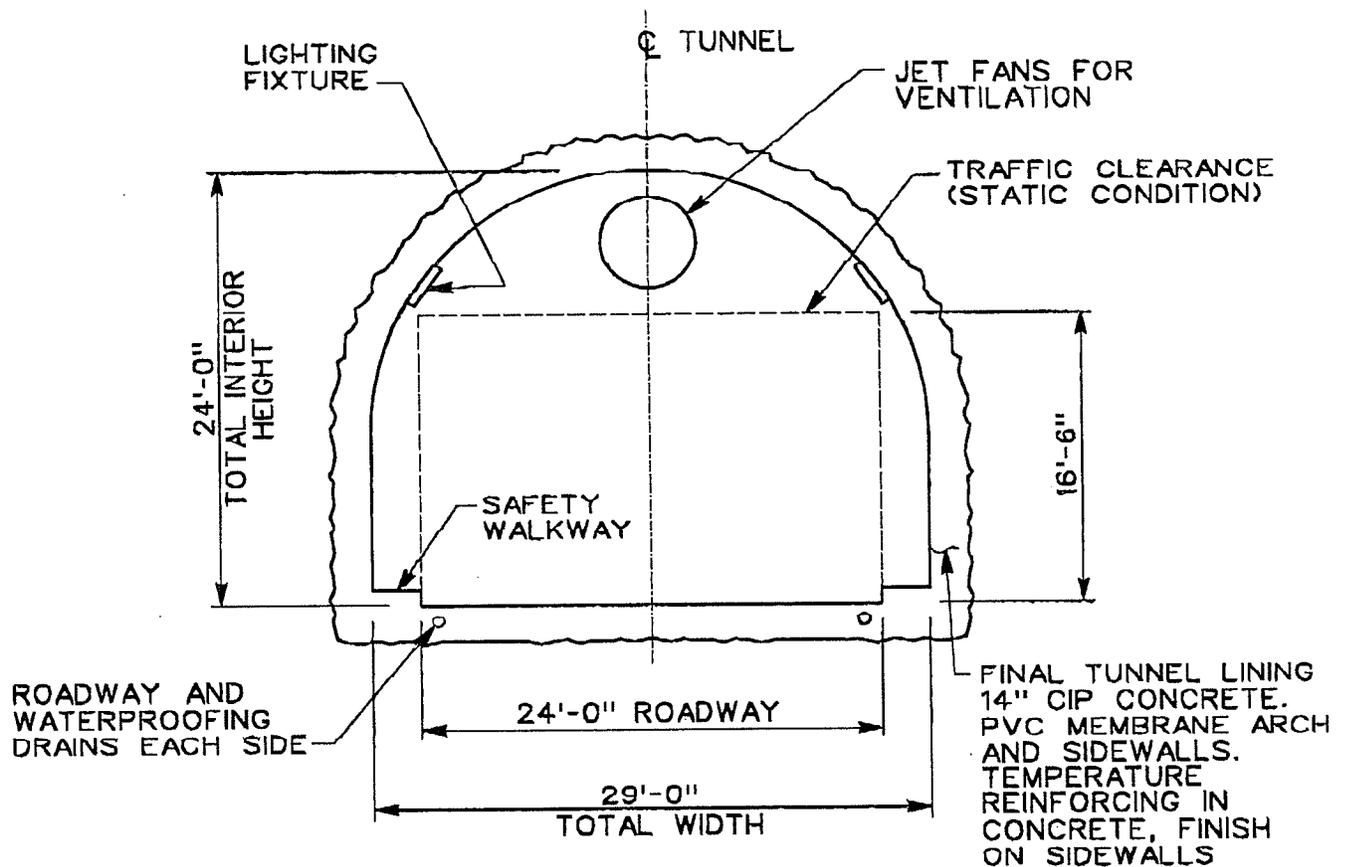


WASTEWATER  
TUNNELS

0 9 10 20 FT  
GRAPHIC SCALE

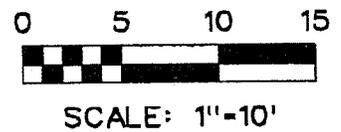
COMPARISON OF TUNNELS - HONOLULU, HAWAII

DRAWN BY D.H.	<b>JACOBS ASSOCIATES</b>	<b>WAIANAE TUNNEL</b>	JOB NO. 3703
DATE 07/01	<b>Engineers/Consultants</b> 500 SANSOME STREET SAN FRANCISCO, CA 94111-3275		<b>COMPARISON OF TUNNELS</b>

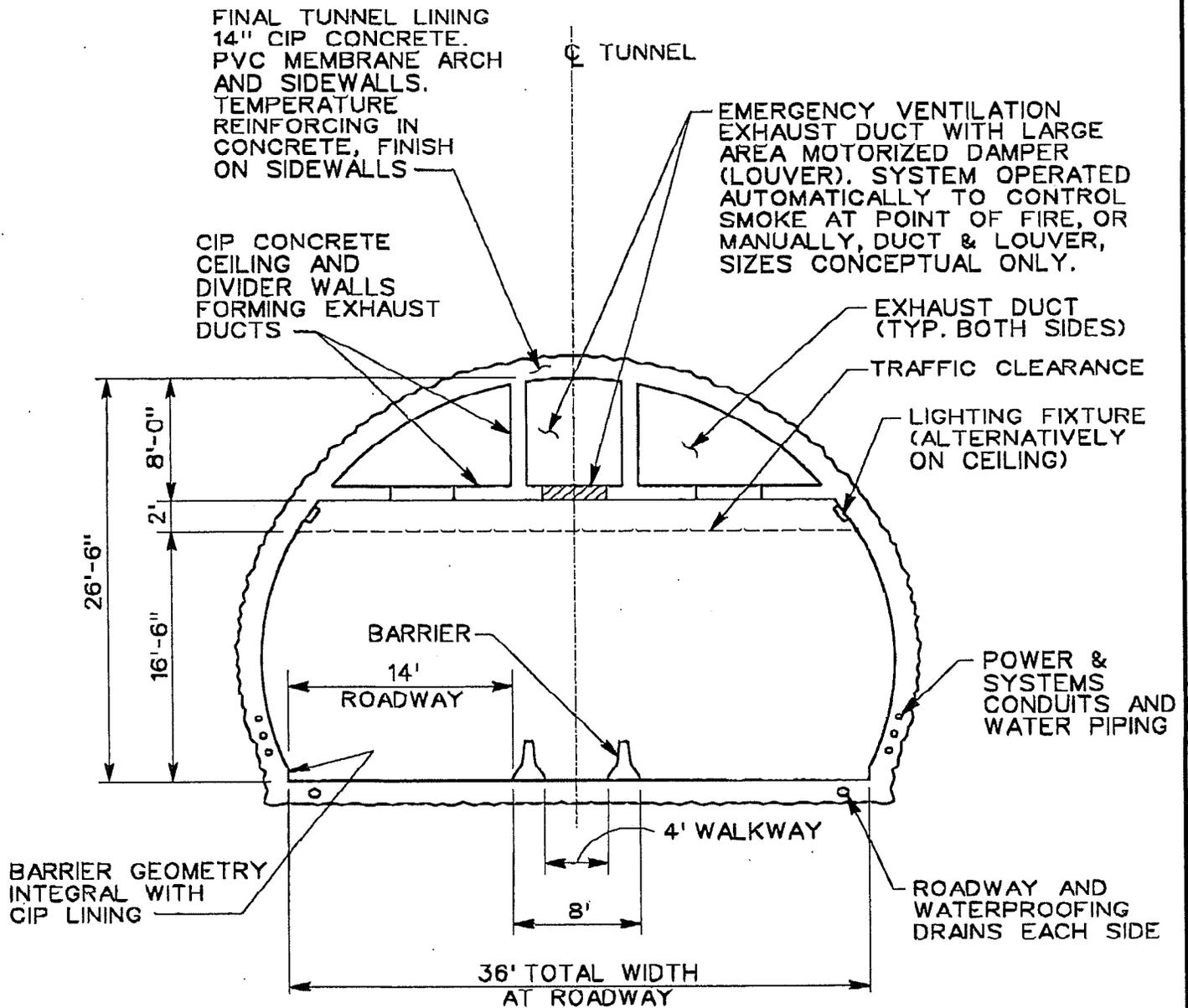


**NOTE:**

INITIAL GROUND SUPPORT: PATTERN DOWELS AND SHOTCRETE VARIES WITH GROUND CONDITIONS.



DRAWN BY D.H.	<b>JACOBS ASSOCIATES</b> Engineers/Consultants 500 SANSOME STREET SAN FRANCISCO, CA 94111-3275	<b>WAIANAE TUNNEL</b>	JOB NO. <b>3703</b>
DATE 08/01		<b>CONCEPTUAL TWO-LANE UNI-DIRECTIONAL TUNNEL CROSS SECTION</b>	FIGURE 2



**NOTE:**

INITIAL GROUND SUPPORT:  
PATTERN DOWELS AND  
SHOTCRETE VARIES WITH  
GROUND CONDITIONS.

DRAWN BY D.H.	<b>JACOBS ASSOCIATES</b> Engineers/Consultants 500 SANSOME STREET SAN FRANCISCO, CA 94111-3275	<b>WAIANAE TUNNEL</b>	JOB NO. 3703
DATE 08/01		<b>CONCEPTUAL TWO-LANE BI-DIRECTIONAL TUNNEL CROSS SECTION</b>	FIGURE 3