HONOLULU RAPID TRANSIT PROGRAM

TASK 17.01

KING STREET SUBWAY ALIGNMENT STUDY

Prepared for

DEPARTMENT OF TRANSPORTATION SERVICES
OFFICE OF RAPID TRANSIT

City and County of Honolulu
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Prepared by

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1.0 EXECUTIVE SUMMARY

The *King Street Alignment Study* is a conceptual-level design for an alternative subway alignment through downtown Honolulu. This alternative simultaneously satisfies the system requirement while reducing the cost of construction relative to the originally proposed Hotel Street Subway.

The *Hotel Street Subway Study Report*, dated July 1991, is a conceptual-level planning, architectural and engineering feasibility study that was performed as a prelude to the *Hotel Street Subway Design, Supply, and Construction Request for Proposals* (RFP). The results of this study indicated that the construction cost of the subway segment through downtown Honolulu would be much greater than originally estimated. This was also confirmed by prospective contractor proposals that were received in response to the RFP. As a result of these findings, it was determined by the Office of Rapid Transit that the Hotel Street Subway segment would not be financially feasible.

Based on the results of the Alternative Analysis/Draft Environmental Impact Statement (AA/DEIS), conceptual engineering studies to date, comments received during the public review process, and determinations made in the Request For Proposal (RFP) process, the City Council amended the Locally Preferred Alternative (LPA) by Resolution Number 91-241, CD-1. This resolution replaced the Hotel Street Subway with an aerial alignment that generally follows Nimitz Highway, Pohukaina Street, and Ward Avenue. This resolution also included provisions that replaced the University terminus at Metcalf Street with a Lower Campus (Quarry) terminus and for budgetary and environmental reasons eliminated the Waikiki "pinched loop" from further consideration.

The proposed King Street Subway alignment would transition from an aerial guideway to an underground facility using the original Hotel Street Subway Ewa Portal, which is located approximately 1,650 feet Ewa of the Nuuanu Stream. The underground alignment would extend in the Koko Head direction beneath private property and cross beneath the Nuuanu Stream approximately 150 feet makai of the King Street bridge. Beyond the Nuuanu Stream, the subway would generally follow King Street through downtown Honolulu intersecting the original Hotel Street alignment near Kapiolani Boulevard and South King Street. The King Street subway would transition to an aerial structure at the previously proposed Hotel Street Subway Koko Head portal located between Dreier Street and Ward Avenue.

Several constraints within the study limits influence the geometric alignment of the proposed subway. The requirement to minimize right-of-way acquisition mandated that a maximum 6 percent grade be used at each of the subway portals where the guideway transitions from an aerial structure to a subway. In addition, right-of-way impacts were minimized by establishing a horizontal alignment that follows the centerline of King Street. The width of King Street varies from 56 to 84 feet, and as a result, the horizontal alignment of the subway has several curves with short spiral lengths that limit train speed to approximately 30 miles per hour.

The geology encountered along the King Street Subway alignment is mixed and highly complex when appraised from the perspective of underground construction. The major geological

constituents include lava flows, alluvial deposits, organic deposits, lagoonal deposits, reef deposits, beach deposits, cinder sands, volcanic tuff, and man-made fill. This environment is further complicated by the local groundwater elevation, which is approximately 4 to 22 feet below the ground surface. These conditions will strongly influence the methods proposed for subway construction, and the final design characteristics of the permanent structure.

The Honolulu Series basalts are extraordinarily hard; however, the rest of the geological materials are relatively soft. Tunneling and excavation equipment is most efficiently designed and effectively utilized when it is operated in a homogeneous environment. An analysis of the geologic profile on King Street revealed that the extremely hard basalts were found at minimum depths of approximately 50 feet below grade. The elevation of this basalt layer was used as a constraint when the vertical profile of the proposed subway tunnel was established. By avoiding the basalt formations, mixed-faced tunneling would be circumvented and construction difficulties and related construction costs would be reduced.

Ground displacement, settlement, and deflections are of concern, particularly in soft or uncemented soils along the developed King Street alignment. It is imperative that the design and construction carefully consider and monitor potential ground displacements in order to mitigate the possibility of inflicting structural damage on adjacent sensitive buildings. As stated earlier, the complex geology consists of a nonhomogeneous mix of materials. The cemented to uncemented reef deposits are interwoven with alluvial clays, silts and sandy gravels. The disjointed nature of this material will make the magnitude and profiles of any settlement troughs very difficult to predict.

In general, the tunneling environment along the King Street alignment was found to be better than to the Hotel Street Subway alignment for the following reasons:

- The basalt flow tends to descend to lower elevations as the land surface extends in the makai direction towards Honolulu Harbor. Consequently, it appears that a mixed-faced tunneling environment involving boulders, very soft organic silts, and very hard basaltic rock can be avoided without adversely impacting the vertical profile of the guideway alignment. Along Hotel Street, the geologic profile of the basalt was not as favorable because the estimated elevation of the basalt negatively impacted the established tunnel profile and some mixed-faced tunneling was anticipated.

- A significant length of the King Street tunnel will be mined through several geological formations. The primary components include the organic deposits near the Nuuanu Stream, alluvial, sands and silts, boulders, cobbles, and gravels overburdened by reef deposits between River and Richards streets, followed by cemented and uncemented reef deposits for the remainder of the alignment. Lenses and layers of beach sand and hard volcanic tuff are interspersed between the primary geologic components, and an erosional channel that is filled with a combination of boulders, alluvial silts and volcanic cinders lies near the King and South streets intersection. However, the overall geologic characteristics were found to be less complex than the corresponding properties for Hotel Street.

- The King Street public right-of-way, measured from face-to-face of building or property line, varies in width from 56 to 84 feet. At the proposed King Street Subway station locations, the right-of-way width is at a minimum, 10 feet wider than the typical width of 50 feet found along Hotel Street. The increased width eases construction difficulties and generally reduces the costs associated with building protection.

The structural configurations presented in this report are all suitable for the King Street alignment when evaluated relative to the geometric and physical constraints that exist within the subway project limits. The decision to use mined tunneling as opposed to cut-and-cover construction for the line tunnels was justified by the desire to minimize disruption to surface activities during the construction of the transit system. For this reason, the order-of-magnitude cost estimate was based on a twin-circular tunnel bore constructed with an Earth Pressure Balance Tunnel Boring Machine. For comparison, a cost estimate for cut-and-cover construction was also prepared for the King Street alignment.

The King Street Subway stations are an improvement over the Hotel Street Subway stations. The King Street stations are of a conventional center-platform configuration while the Hotel Street Subway stations have stacked platforms and restricted circulation elements resulting from the narrowness of the Hotel Street right-of-way. The King Street Subway stations allow for efficient passengers handling and orientation. In addition, the construction of the stations would be relatively straight forward in comparison to the Hotel Street stations.

Ridership estimates for the King Street alignment were prepared using the forecasting model used in the Preliminary Engineering phase of the Honolulu Rapid Transit Program. The ridership estimates for the No-Build, Transportation System Management (TSM), and the Locally Preferred Alternative (LPA), are all the same estimates that were used in the Supplemental Draft Environmental Impact Statement (SDEIS).

Systemwide ridership is projected to increase by approximately 3,500 passengers per day if the proposed alignment along Nimitz Boulevard and Pohukaina Street is shifted to King Street. This is a 1.1% difference in systemwide ridership.

The long-term environmental impacts would be similar for the Hotel Street Subway and King Street Subway alternatives. The greatest differences would occur in the impacts to business displacement and traffic. The long-term impacts for traffic would be greatest with the Hotel Street Subway alignment since the bus traffic would be permanently rerouted from the Mall. The Hotel Street Subway business displacements (26 to 66 businesses) would generally be greater than the business displacements (29 businesses) for the King Street Subway alternative.

If the King Street Subway alignment were selected as the preferred alternative for the Honolulu Rapid Transit Program, the schedule for the SDEIS would be delayed up to fourteen months.

An order-of-magnitude cost estimate has been prepared for the *King Street Subway Alignment Study*. The construction cost estimate includes expenditures pertaining to demolition, utility relocation, street modifications, underpinning, subway and passenger station facilities, landscaping, final engineering, project management, and a contingency allowance. This cost estimate specifically excludes system-wide elements, preliminary engineering, City financing and operating expenses, and any funds dedicated as a project reserve for change orders or scope enhancements. The scope of this estimate is identical to the scope presented in the *Hotel Street Subway Study Report*, and therefore, the represented "TOTAL" values are comparable. The total estimated construction cost for the King Street Subway is $402 million.

The project schedule for the Honolulu Rapid Transit Program should be evaluated prior to making a final assessment regarding the proposed King Street Subway alignment alternative. The currently proposed fixed guideway system, inclusive of the Nimitz Option, is scheduled to be completed and open to revenue service by 1997. Design and construction of a King Street Subway segment would take approximately three years. If the procurement process for a subway contract was initiated by June of 1992, the availability of the transit system would be delayed by approximately one year. The financial impact of this delay requires an analysis of parameters that include inflation, interest rates, and available funding mechanisms.

The proposed King Street alignment solution has advantages relative to the Hotel Street Subway, particularly with respect to the subsurface geology, geometric alignment constraints, available passenger station configurations and constructability issues. In addition, the total capital cost of the King Street subway is approximately 18 percent less than the Hotel Street Subway. A detailed cost comparison of subway alternatives is presented in Section 11. Project schedule delays and construction cost are both significant obstacles associated with any subway alignment through downtown Honolulu.

2.0 INTRODUCTION

Based on the results of the Alternative Analysis/Draft Environmental Impact Statement (AA/DEIS), conceptual engineering studies to date, comments received during the public review process, and determinations made in the Request For Proposal (RFP) process, the City Council amended the Locally Preferred Alternative (LPA) by Resolution Number 91-241, CD-1. This resolution replaced the Hotel Street Subway with an aerial alignment that generally follows Nimitz Highway, Pohukaina Street, and Ward Avenue. This resolution also included provisions that replaced the University terminus at Metcalf Street with a Lower Campus (Quarry) terminus and for budgetary and environmental reasons eliminated the Waikiki "pinched loop" from further consideration. The resolution adopted by the City Council also required the Office of Rapid Transit to evaluate the feasibility of a downtown subway along the King Street alignment.

2.1 General System Description

The current system configuration includes 22 passenger stations along 16.0 miles of fixed guideway structure. Consistent with the initial LPA document, the alignment originates at the Waiawa Station and extends to the University of Hawaii. The significant variations entail; elimination of the Waikiki "pinched-loop," replacement of the Hotel Street Subway segment with an aerial guideway designated as the "Nimitz Option 2," and shifting the location of the University of Hawaii terminus station, which is now designated the University/Quarry Station.

The Nimitz option is an aerial alignment that begins near Dillingham Boulevard at Station 680+00, it crosses private property and extends along the median of Nimitz Highway. Between Richards and Punchbowl streets the alignment makes an "S" curve, swings in front of the Federal Building and continues along the makai side of Pohukaina Street. The guideway alignment turns at the intersection of Pohukaina Street and Ward Avenue and extends along the Koko Head side of Ward Avenue towards Waimanu Street. At the intersection with Waimanu Street the alignment turns in the Koko Head direction to intersect the original LPA alignment at Station 773+50.

Five aerial stations would be positioned along the Nimitz Alignment. The passenger stations are identified as; Kaaahi Street, Nimitz/Smith, Nimitz/Fort, Pohukaina/South, and Ward Stations. The station names are descriptive of their respective locations.

2.2 King Street Subway

The King Street Subway alignment has been proposed as an alternative subway solution, primarily to evaluate cost advantages that may be realized due to tunneling conditions that appear more favorable along King Street as opposed to Hotel Street. The King Street alternative alignment would traverse downtown Honolulu with approximately 1.5 miles of tunnel and serve the City with two subway stations. For purposes of this study, orientation of the subway alignment will be denoted as Ewa (Waiawa Station direction) and Koko Head (University/Quarry Station direction).

The proposed King Street guideway alignment will transition from an aerial structure to an underground facility using the original Hotel Street Subway Ewa Portal which is located approximately 1,650 feet Ewa of the Nuuanu Stream. The underground alignment would extend in the Koko Head direction beneath private property and cross beneath the Nuuanu Stream approximately 150 feet makai of the King Street bridge. Beyond the Nuuanu Stream, the subway would generally follow King Street through downtown Honolulu, intersecting the original Hotel Street Alignment near Kapiolani Boulevard and South King Street. The King Street Subway would transition to an aerial structure at the previously proposed Hotel Street Subway Koko Head portal located near Dreier Street.

The King Street underground segment would encompass the highest ridership passenger stations for the entire system and mitigates or eliminates the severe environmental impacts associated with an above-grade crossing through the City of Honolulu. The major subway components include two portals, two passenger stations, and connecting tunnel sections.

The objective of this study is to ascertain the physical conditions along the subway alignment, select a construction method, develop conceptual-level tunnel and station design solutions, analyze environmental impacts, operating characteristics and capital cost, and in conclusion, comment on the overall feasibility of a King Street Subway.

The *King Street Subway Study* is based on a compilation of activities that have been performed in support of the conceptual level design presented in this document. The tasks include:

- Preparation of topographic base maps that illustrate existing right-of-way, building, drainage, and utility information.

- Geotechnical exploration of the subsurface and groundwater conditions along the proposed alignment. Evaluation of geological data and an assessment of engineering properties relevant to tunneling conditions.

- Preparation of prototypical subway stations and running tunnel cross sections that meet functional and structural requirements.

- Evaluation of construction methods, patronage projections, environmental impacts, construction costs, and schedule impacts.

- Review of the proposed King Street Subway alternative with City representatives, and formulation of a feasibility assessment to execute the project.

The results from each activity were used to generate the conceptual-level design solution presented in this study.

3.0 KING STREET ALIGNMENT

3.1 Introduction

This section of the study describes the transit system alignment as it descends from the aerial structure in the vicinity of Dillingham Boulevard to the twin tunnel subway under King Street and ascends to an aerial structure before crossing over Ward Avenue. It also identifies the constraints that have influenced the design.

3.2 Alignment Constraints

The alignment has several significant constraints that influenced the design. Vertical clearance criteria for the guideway and support structures requires that the top of rail be at least 24.5-feet above the traffic lanes.

Second, the portal structure must not interfere with Iwilei Road or Nimitz Highway. In addition, the tunnel must pass under the Nuuanu Stream.

The tunnel must remain inside the King Street right-of-way. The right-of-way varies from 56 feet to 58 feet between River Street and Bethel Street. It increases up to 84 feet wide from Bethel Street to Kapiolani Boulevard. The right-of-way restrictions are further compounded by historic buildings at the Ewa end and high rise structures Koko Head of Bethel Street. Several curves exist on King Street that the guideway alignment will have to match as closely as possible and still provide sufficient tangent lengths at the station locations.

At the Koko Head end, the tunnel portal must not interfere with Kapiolani Boulevard or Dreier Street, and the guideway must cross over Ward Avenue with at least 17-feet of clearance to the bottom of the structure.

3.3 Alignment Geometry

The King Street Tunnel alignment would begin near the end of Section 3 on Dillingham Boulevard. At this location there is a 13 foot 11 inch separation between the track centerlines. The guideways descend a 6 percent grade and turn right, through a 1,500-foot radius curve, entering a portal near Kaaahi Street. The separation between the guideways is increased through the curve by continuing the up-track curve slightly further than the down-track curve. The increased length of curve will introduce a small diversion angle between the two guideways. A 5,000-foot radius curve to the left aligns the tunnels with the centerline of King Street. The up-track curve length is again slightly longer than the down-track curve in order to align the tunnels parallel and 33 feet apart. The wider separation is needed for the center-platform stations.

The tunnel continues through curves of 5,000- and 3,000-foot radii, 40 to 50 feet below the street, to the King/Bethel Station between Bethel Street and the Fort Street Mall. Following the King

Street alignment, the guideway proceeds to the King/Punchbowl Station under the intersection of King Street and Punchbowl Street.

Leaving the Punchbowl Station, the tunnels turn left through a 6,000-foot and right through a 400-foot radius curve onto Kapiolani Boulevard. As Kapiolani turns left, the tunnels continue essentially straight off of the street right-of-way. In addition, the tunnels begin to converge to the standard 13-foot 11-inch separation for the aerial guideways at this location. The up-track and down-track turn right and left respectively through a 10,000-foot-radius curve and enter the Koko Head portal at Dreier Street. The guideways ascend at a 6 percent grade, turn left through a 1,000-foot curve, cross over Ward Avenue, and enter the Neal Blaisdell Center (NBC) Station on Waimanu Street.

3.4 Utilities

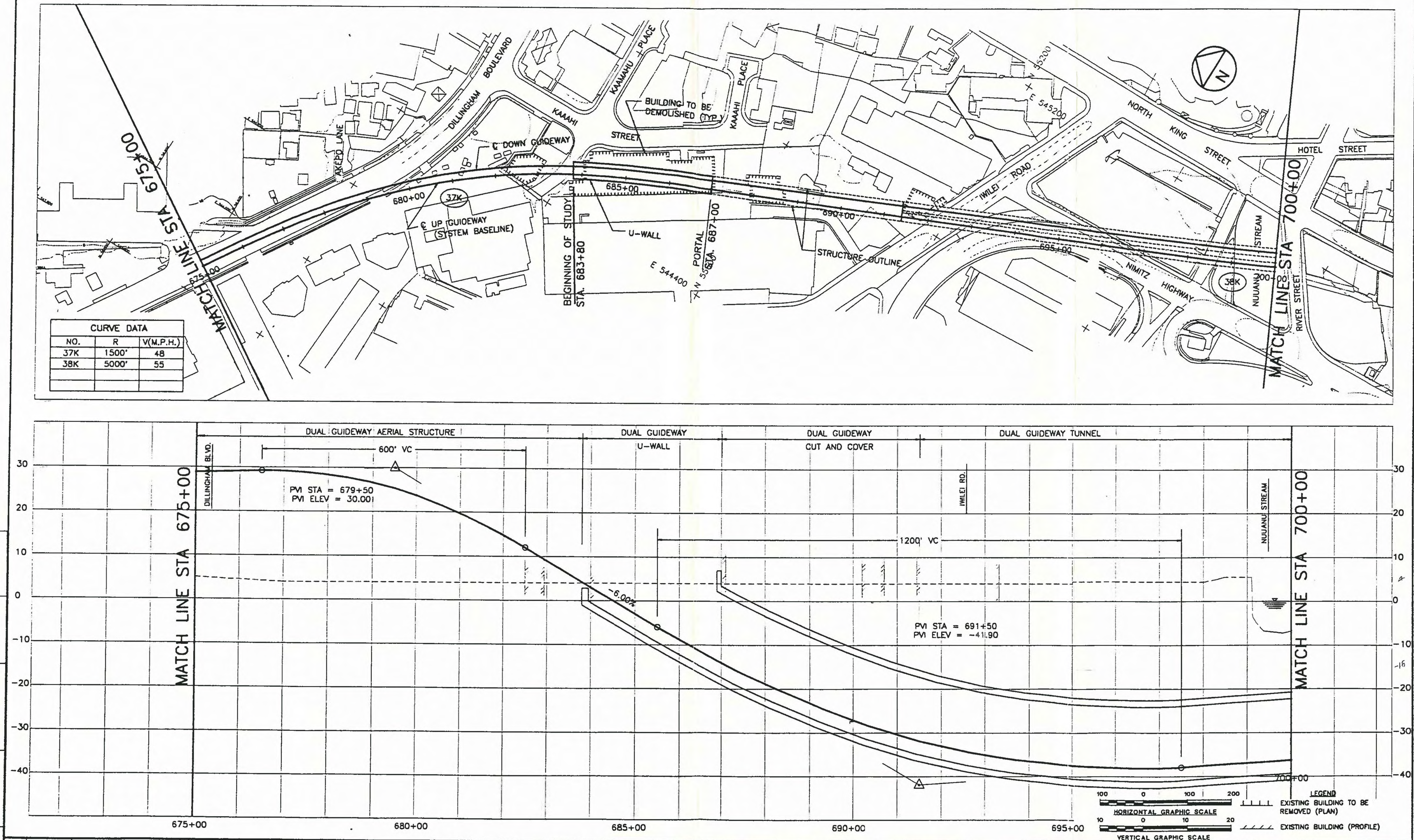
Utility conflicts with the subway construction consist of a 48-inch drain line and AT&T fiber optic cables that pass through the King/Punchbowl Station site where cut-and-cover construction is required. Two 46 kV lines that cross King Street at Richards Street and a 10 x 8-foot HCDA box drain along Kapiolani Boulevard between King Street and Cooke Street are above the bored tunnels and should not be affected by the subway construction.

3.5 Conclusions

The change in rail profile from an elevated structure to a subway within a predefined area resulting from constraints previously discussed mandated a maximum grade of 6 percent at each of the subway portals. The total outside width occupied by the twin tunnels is 52 feet. The alignment closely follows the center of King Street for most of its length. The width of King Street varies from 56 to 58 feet between River Street and Bethel Street and increases up to 84 feet from Bethel Street to Kapiolani Boulevard.

The selected location of the King/Bethel Station is within a curve along the street alignment. The need for station platforms to be on tangent rail alignment resulted in the shift of the tunnel alignment toward the makai side of the street at the Koko Head end of the station. Further investigations of existing building foundations may require alignment and station modifications at this location.

Cut and cover construction will be required within King Street at both King/Bethel and King/Punchbowl stations and in Kapiolani Boulevard between Clayton Street and Dreier Street at the Koko Head portal. Horizontally, there are several curves with short spiral lengths that limit train speed to 30 mph or less.



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Drawn by:
Checked by:
Approved by:

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DEPARTMENT OF TRANSPORTATION SERVICES
HONOLULU RAPID TRANSIT PROGRAM

SUBMITTED: ____________ APPROVED: ____________

PLAN AND PROFILE
STA 675+00 TO STA 700+00
KING STREET SUBWAY

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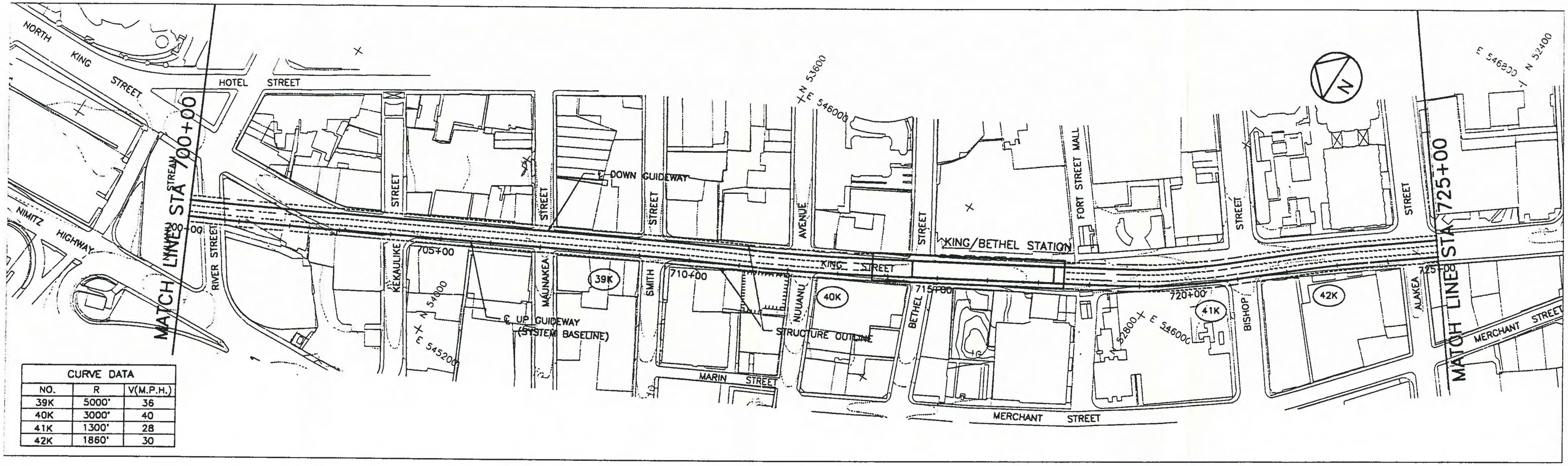
REV. SHEET NO. SK 3.1
SCALE 1"=40' DATE



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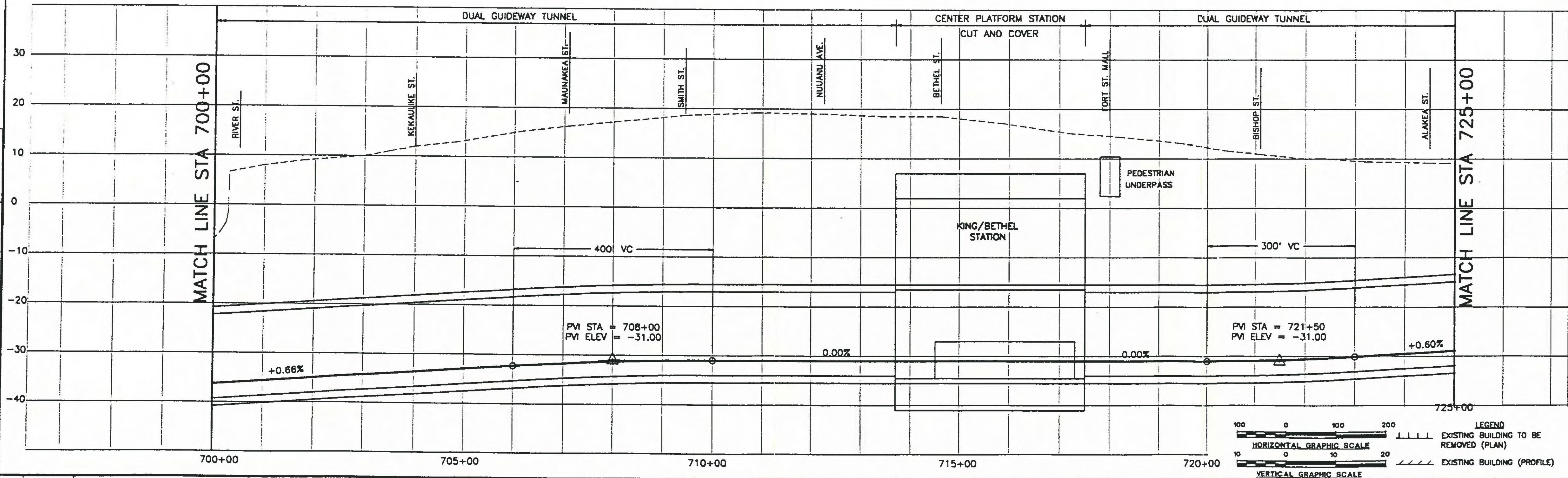

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HONOLULU RAPID TRANSIT PROGRAM

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PLAN AND PROFILE
STA 700+00 TO STA 725+00
KING STREET SUBWAY

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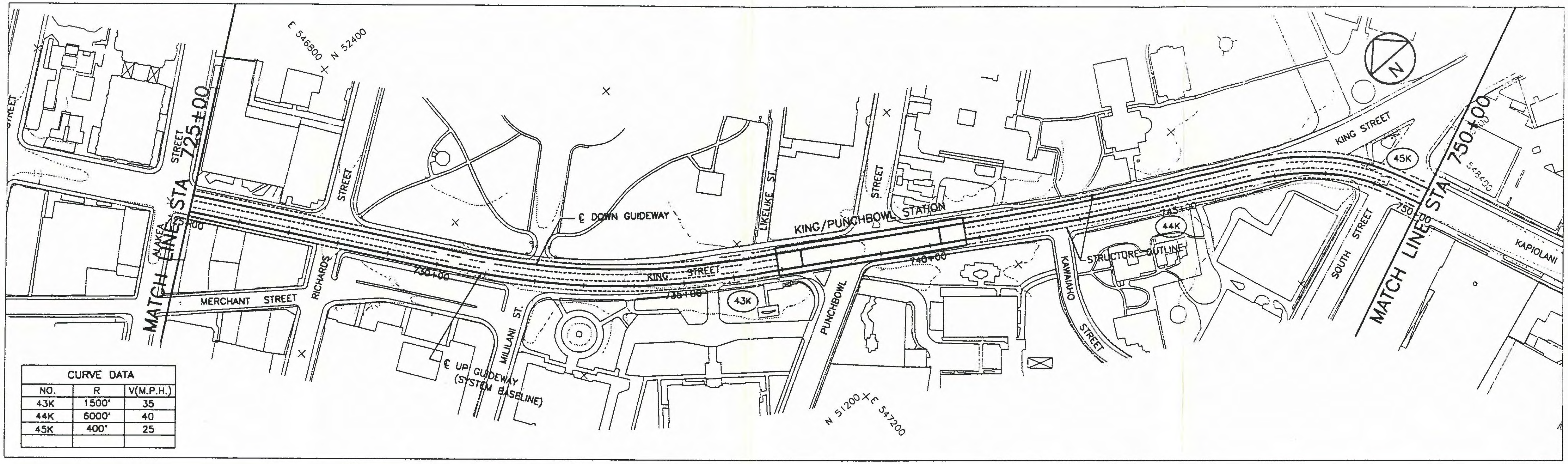

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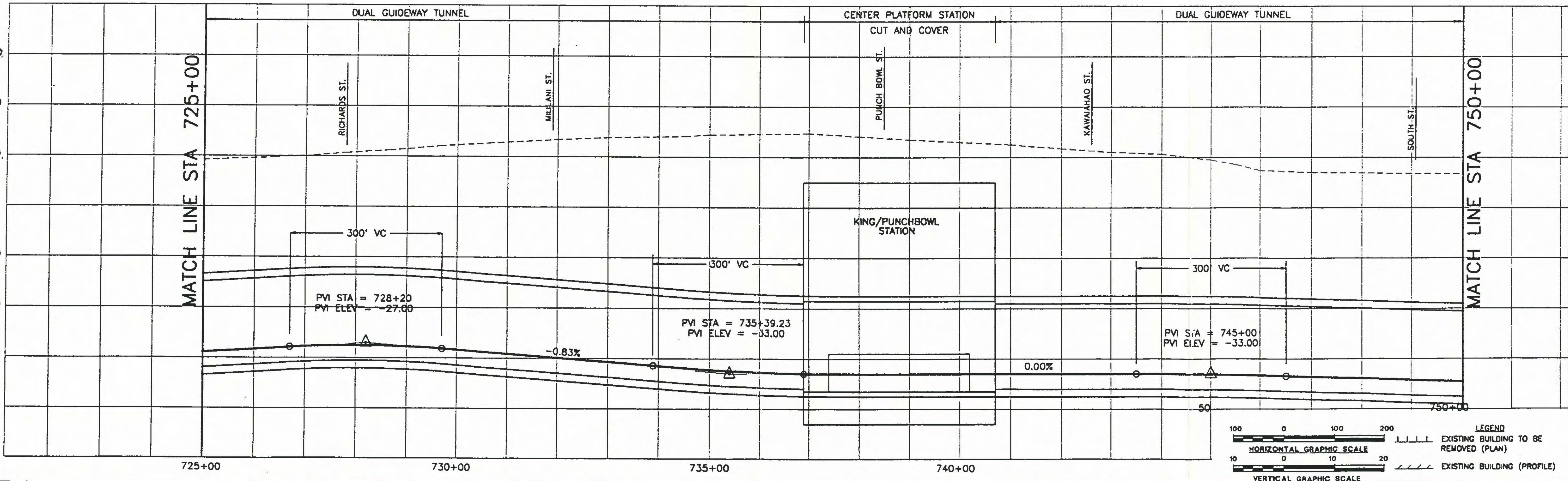

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DEPARTMENT OF TRANSPORTATION SERVICES
HONOLULU RAPID TRANSIT PROGRAM

SUBMITTED: ____________ APPROVED: ____________

PLAN AND PROFILE
STA 725+00 TO STA 750+00
KING STREET SUBWAY

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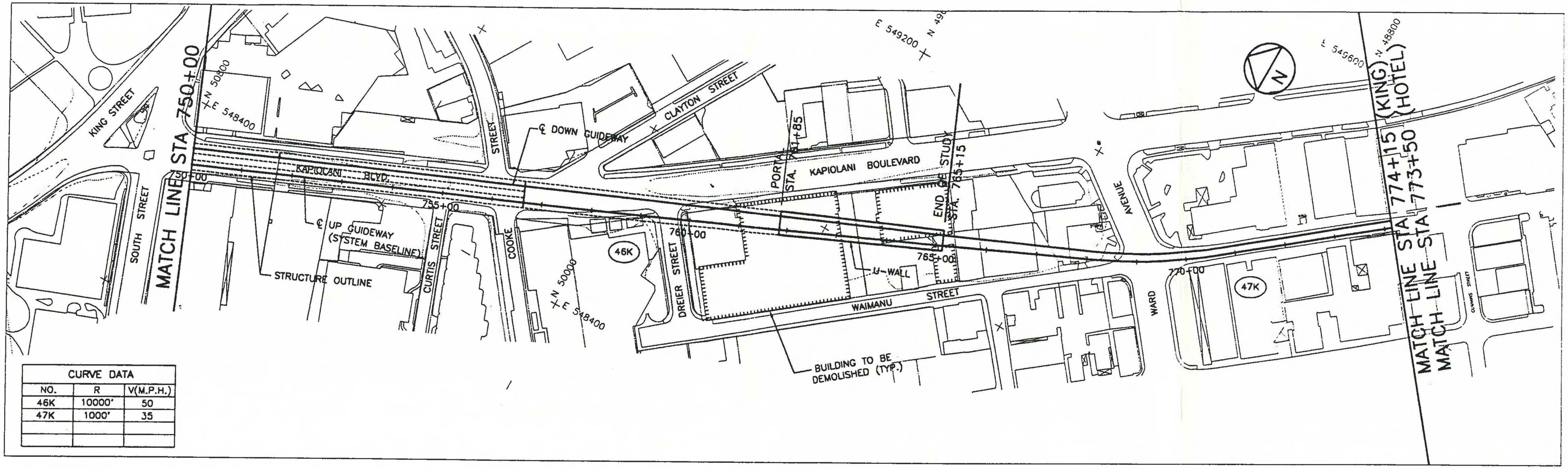

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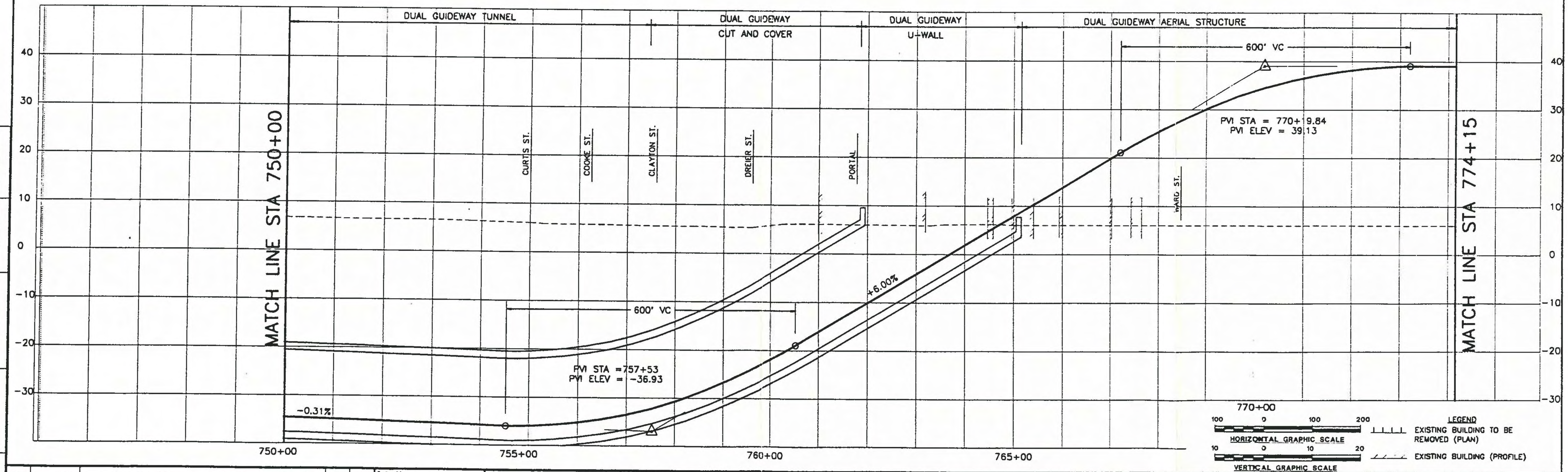

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HONOLULU RAPID TRANSIT PROGRAM

SUBMITTED: ______ APPROVED: ______

PLAN AND PROFILE
STA 750+00 TO STA 773+50
KING STREET SUBWAY

CONTRACT NO.
DRAWING NO. K.AL.A.004
REV. SHEET NO. SK 3.4
SCALE 1":40' DATE

AR00051577

4.0 GEOLOGICAL CONDITIONS

4.1 General Description

4.1.1 The Geology of the Hawaiian Archipelago

The Hawaiian Islands are part of a northwest-southeast archipelago some 1,600 miles long, stretching from Midway Island to the "Big Island" of Hawaii. The islands were built up by volcanic lavas erupting from the sea bottom over a stationary "hot spot" in the earth's crust until each emerged at sea level, about 18,000 feet from the ocean depth, and continued to build to heights of many thousands of feet. Thus, from base to crest, they are among the highest mountains in the world. Generally, these eruptions were a series of basalt flows of remarkable chemical uniformity that emerged with little violence. A continuing shift in the Pacific Tectonic Plate gradually moved each island to the northwest, making room for a new volcanic island to build up over the "hot spot."

The five main islands that make up the State of Hawaii are situated in the southeast end of the Hawaiian Archipelago. From oldest to youngest, these islands are Kauai, Oahu, Molokai, Maui, and Hawaii. On the "Big Island" of Hawaii, the island-building process is still going on with almost continuous eruptions of lava to this day. A submerged sea mount, which will someday be a new island, just off the southeast coast of the "Big Island" has almost emerged above sea level.

As each island moved northwest away from the "hot spot" and ceased eruptions, a period of quiescence began that lasted several million years. Coral reefs were formed around the islands in the warm Pacific Ocean waters while sea action broke down the basalts and formed them into black sands that can still be seen on the newer islands. Eventually, the basalts were chemically weathered to depths of hundreds of feet, and clay minerals were formed by tropical weathering processes. During glacial and interglacial periods, the seas rose and fell and the islands sank and spread laterally. This movement led to rejuvenated stream cutting accompanied by the formation of swamps and associated organic lagoon deposits in quiet waters behind the shoreline.

Recent volcanic activity occurred on many islands along vents and outlets unrelated to the original formation of the island. These eruptions were often violent with spectacular explosions and fire fountains. Lava flows, cinder, tuff, and ash deposits from these eruptions became intermingled with the near-shore coral, beach sands, and lagoonal deposits.

4.1.2 The Geology of Oahu and Honolulu

Oahu was formed by the coalescing of two separate volcanic islands. The Waianae Volcano, in the northwest, moved away from the "hot spot" and ceased eruptions first, and the Koolau Volcano, in the southeast, actively erupted until the Koolau Basalts filled the sea between the two islands. The present Schofield Plateau in the center of Oahu is the remnant of the Koolau

Basalts as they lapped over the older Waianae Volcano basalts that form the mountain range on the west of Oahu.

After the Koolau eruptions ceased, no further volcanic activity occurred on Oahu for about two million years. The island slowly sank of its own weight, some 1,200 feet, spreading laterally into the soft sea beds. Coral reefs formed, and wave action created white sand beaches from coral fragments. Various silty lagoons formed near the beaches while the sea level rose and fell during glacial and interglacial periods. The basalt lava flows in the high ground weathered, forming soil to depths of hundreds of feet. Tropical rains eroded the highlands, removing the silt and clay soils derived from the older weathered basalts and carrying them down toward the beach.

Abruptly, as little as 50,000 years ago, a new series of volcanic eruptions began: The Honolulu Volcanic Series of about 30 separate events. These eruptions were much more volatile than the monotonous series of the older Koolau lava flows and took place near Pearl Harbor and Honolulu, violently ejecting cinders, ash, and tuff that fell to the ground and were welded into firm beds.

Today, the geology around Honolulu is superficially simple: the volcanic basalt island of Oahu is flanked by coral. However, the interfingering of coral, beach sands, and lagoon deposits with recent Honolulu Volcanic Series ash and tuff and occasional alluvial deposits of boulders, silt, and clay carried down from the high ground make the microgeology highly complex.

4.1.3 Geology of the King Street Subway

The information pertaining to the geology along the King Street Subway alignment is documented in the *Preliminary Geotechnical Exploration - King Street Subway Alignment* report dated February 1992, which was prepared in support of this subway study. The Geological Cross Section drawings, designated as plates 4.1 and 4.2 have been included for reference, and are located in the pockets following Section 12.

Based on the present subsurface data, the proposed tunnel is expected to encounter organic, reef, alluvial, beach, and cinder deposits. In isolated locations, the tunnel invert may encounter hard volcanic tuff. The soils and rocks found along the proposed King Street tunnel alignment have been grouped into nine (9) main stratigraphic units. The soils are described in accordance with the Unified Soil Classification system and are as follows:

> Lava flows: Typically dense to very dense, hard, highly to slightly fractured, fresh to moderately weathered, vesicular basalt. Zones of weathered clinker and broken material were found at the top of some flows. Cavities 0.2 to 0.8 feet wide were encountered in at least one boring (HB-3). Clayey silt was present along some of the joints and fractures in the basalt. Lava flows encountered in this study probably belong to the Honolulu Volcanic Series.

> Alluvial deposits: Primarily saturated soft to stiff sandy and clayey silts, silty loose to very dense sandy clays, and silty sandy gravels and hard nested and dispersed basaltic cobbles and boulders, and cemented nodules are present and should be expected in tunneling through the alluvial deposits.

Organic deposits: Primarily saturated very soft to medium stiff, highly compressible organic silty sands and sandy silts, containing organic fibers and decayed wood fragments. Near Nuuanu Stream, these organic deposits may also contain flood deposited pebbles, gravels and boulders.

Lagoonal deposits: Consists predominantly of very soft to medium stiff, highly compressible sandy and gravelly silt and clay and very loose to loose silty sand.

Reef deposits: Three types of reef deposits were encountered in the exploratory borings. All these units had refusal blow counts (N > 50 blows per foot) and variable cementation. In open cut some blasting or excavation by mechnical equipment may be required to excavate the coral reef deposits.

a. Coral (Type I): Formed in-place, hard, slightly weathered to unweathered, coral reef. Two types of in-situ coral (Type I) are present, namely colonial and singular coral.

b. Coral (Type II): Reworked and recemented coral fragments. Primarily gravel and cobble-sized coral fragments in a cemented to weakly cemented sandy silty matrix.

c. Coralline Sand and Gravel: Generally consists of locally cemented to uncemented calcareous sand (sandstone) and coralline gravel sometimes in a clayey to silty matrix.

Beach deposit: Primarily loose to medium-dense silty fine sand and sand deposits, usually interbedded or associated with reef deposits. Some of the beach deposits are cemented and others contain gravel.

Cinder sands: Consists primarily of poorly graded volcanic sand and silty sand. The cinder sands obtained by the drive samplers are generally lose to medium dense. In local areas, particularly where the deposit is relatively thick, such as within the infilled channel under Kapiolani Boulevard, they appear to be fused or cemented.

Volcanic tuff: Typically is hard (rock) to fused (cemented) angular sand, closely to moderately fractured, thin bedded and contains cobbles and boulders. The upper portion of the tuff is highly to moderately weathered and closely fractured.

Fill (man-made): Consists generally of sandy gravelly silt, silty sand and sandy gravel. The gravel component is predominately composed of coral or basalt. The fill contains cobbles and may have boulders.

For the purpose of discussion, the engineering geology of the tunnel alignment can be generalized and described in seven (7) segments:

1. Kaaahi Street to Kekaulike Street
2. Kekaulike Street to King/Bethel Station

3. King/Bethel Station
4. King/Bethel Station to King/Punchbowl Station
5. King/Punchbowl Station
6. King/Punchbowl Station to Kapiolani Boulevard/South Street
7. Kapiolani Boulevard/South Street to Waimanu Street.

4.2 Subsurface Conditions Along the King Street Alignment

4.2.1 Kaaahi Street to Kekaulike Street

This section of the subway alignment is approximately 2,000 lineal feet long, on the northern portion of the King Street alignment. This section contains a major erosional feature that incised into basaltic rock and alluvial silts and which was subsequently infilled by organic sandy silt and silty sand, in a backreef lagoonal swamp. Local areas of volcanic cinders and a relatively thin mantle of fill material overlie the organic deposits. The present day Nuuanu Stream appears to flow over the organic deposits, with possible volcanic cinders near the northern wall of the stream. The depth of water inflows from the stream into the underlying soils is not known. Depth soundings at six locations conducted from the King Street and Nimitz Highway bridges on February 14, 1992, revealed that Nuuanu Stream is approximately 4 to 7 feet deep.

A total of 8 borings were drilled as part of this study or other investigation in this section. Two borings for this study, three borings for the Hotel Street Subway project, and borings conducted by others for the 901 River Street and Mauna Kea Street parking structure were drilled near this 2,000-linear-foot section of the subway alignment.

The available subsurface information indicates that the Ewa (west) portal and U-wall excavation would be made through approximately 3- to 8-foot thick surficial fill, cinder sand, and thick deposits of soft to very soft, highly compressible organic sandy and clayey silt.

In this section, the proposed King Street tunnel is anticipated to be constructed in very soft to soft, highly compressible organic sand and silt below the water table.

During the field exploration (January, 1992) groundwater was encountered at approximately 0.5- to —3-foot elevations.

The available borehole data indicate the following subsurface conditions along this section of the alignment:

Fill: Except along Nuuanu Stream, the surficial fill varies from approximately 4 to 8 feet thick. The fill consists primarily of medium-dense sandy and clayey gravel and loose to medium-dense sandy silt and silty sand. The gravel fraction in these soil units generally consists of coralline and some basaltic fragments.

> Standard penetration test (SPT) "N" values vary between 5 and 19 blows per foot in the silty sand and sandy silts, and 30 and 55 blows per foot in the clayey and silty gravels.

Organic Deposits: Along this section of the subway alignment, the exploratory borings encountered thick organic deposits beneath the surficial fill layer. The organic deposits vary in thickness from approximately 20 to 65 feet. In general, these deposits occupy a preexisting depression or erosional channel.

The organic deposits are dark brown to black in color and consist primarily of organic sandy and clayey silt, sandy silt, and silty and clayey sand with zones containing gravel. These deposits commonly contain shells, organic fibers, and partially decayed wood fragments (approximately 6% to 20%). A strong organic odor was noted in some samples. These deposits are typically soft to very soft and are highly compressible. Standard penetration test (SPT) "N" values generally vary between 1 and 11 blows per foot.

Volcanic cinders: A near-surface lense of dark grayish brown to black volcanic cinder sand was encountered in Boring HB-5, on the north side of Nuuanu Stream. The volcanic cinder deposit contained loose silty medium-grained sand that is saturated and locally cemented. The middle and lower portions of this unit contain tuffaceous gravel.

Occasionally, higher SPT blow counts (11 to 29 blows per foot) have been measured. These higher blow counts may be associated with the presence of gravel layers, wood fragment obstruction or hard cobbles or boulders being pushed aside by the sampler. Although hard cobbles were not sampled or cored within the soft organic soils, drill bit chatter and grinding during wash borings in such soils are indicative of in-situ cobbles or boulders.

A thin layer of very soft, highly compressible peat was encountered in Boring HB-2, between depths of approximately 8 to 12 feet.

Alluvial Deposits: Alluvial deposits were encountered beneath the organic deposits near Kaaahi Street (Borings HB-2 and HB-3), in the west, and Awa Street, Nuuanu Stream, and River Street in the east (Borings 7 and RB-3).

In general, the alluvial deposits consist primarily of brown, stiff to very stiff, clayey and sandy silt, and silty sand with subrounded to subangular pebbles, cobbles and boulders.

Between Borings HB-2 and HB-3, in the proposed Ewa portal area, the thickness of the alluvial silts ranged from about 6 to 19 feet thick, approximately 26 to 34 feet below the existing ground surface. Standard penetration tests (SPT) "N" values vary between 14 and 27 blows per foot indicating stiff to very stiff soils.

In the Iwilei and Awa streets parking lot areas (Borings HB-4 and HB-5), the stiff alluvial soils appeared to have been eroded prior to the deposition of the organic silts, and was not encountered by the two borings drilled in this area along the subway alignment.

Near and probably beneath Nuuanu Stream (Borings 7 and R-3), alluvial silty sand and silts containing hard basaltic boulders form the lower portion of the erosion channel wall from approximately 33 feet below River Street to probably 85 feet just west of Awa Street (below the open parking lot). The buried erosional channel was infilled mainly with organic deposits and recent alluvium. Standard Penetration Test "N" values ranged from 8 to 37 blows per foot, and indicated the presence of medium stiff to hard clayey silt and loose to dense silty sand. The river deposits were found to intercalate with boulder layers approximately 5 to 10 feet thick.

Lava Flows: Vesicular basalts were encountered in all drill holes between Kaaahi Street and Kekaulike Street. The basaltic lava flows are generally dark gray, very fine-grained, slightly weathered to unweathered, hard, and closely to moderately fractured rock. Some clayey silt infillings are present in the fractures, particularly near the top of the unit. Cavities or voids up to 0.8-foot size were encountered in the core holes. The exploratory borings indicate that the top of rock appears to vary approximately between elevations -50 and -95 feet. East of Boring H-3, the rock dips east.

Clinker zones are commonly present near the top and margins of basaltic lava flows in Hawaii. Clinker zones generally contain gravel- to boulder-sized basaltic fragments. The zones are characterized by poor core recovery and very low Rock Quality Designation (RQD) in cored samples. In the interior of the lava flows, the basalt can be very dense and hard and have high strength. Unconfined compressive strength data obtained from basaltic rock samples in this general area during the Hotel Street Subway geotechnical study vary from 7,400 psi to 25,840 psi, and wet density ranged between 174 to 183 pounds per cubic foot.

A sample of the basalt obtained from Boring HB-6, located about 120 feet north of the King Street alternative alignment, at a depth of 75.5 to 76.2 feet was petrographically examined at the University of Hawaii as part of the Hotel Street geotechnical study. Results of petrographic modal analysis show that approximately 85% (by volume) of the rock consists of olivine, pyrozene, and plagioclase feldpsars, with some opaque minerals. The remaining portion of the rock consists of vein quartz (approximately 5%), epidote and zoisite (approximately 5%) and voids (approximately 5%). Accessary minerals were found in the vesicles and not in the ground mass of the sample.

4.2.2 Kekaulike Street to King/Bethel Station

This portion of the subway alignment contains reef deposits overlying alluvial sand, silt, clayey silt, and hard basaltic boulders. Basaltic lava flows may occur at depths of approximately 110 feet or more in this area. Relatively thin deposits of volcanic cinders were deposited on an irregular coral reef surface. A thin layer of fill mantles the cinder deposit.

Three borings (Nos. 9, 10, and 11) were drilled along this approximately 1,200-linear-foot portion of the alignment. Two boring logs for the Mauna Kea Street parking structure redevelopment were also used to interpret the subsurface conditions in this area. The available subsurface information indicated that a preexisting buried channel was cut in the reef and alluvial deposits just north of Kekaulike Street. As discussed in Section 4.2.1, this channel was infilled by very soft, highly compressible organic silt and recent Nuuanu Stream sediments.

On the north end of this section, the contact between the organic deposits and the reef/alluvial deposits is probably located between River Street and Kekaulike Street, beneath some historical buildings. South of the contact, the proposed tunnel is likely to be constructed in mixed-face conditions, consisting of cemented and uncemented reef deposits above springline, and alluvial silty sand, sand, and hard fissured clayey silt below the springline. Southeast of Smith Street, the proposed tunnel will also encounter very loose fine sand (beach deposit), reef deposits, and alluvial sand and silt. During the field exploration (January 1992), groundwater was encountered at approximately 9 to 19 feet below existing ground surface, approximately at or near mean sea level. Within this segment of the alignment, the geology consists of the following materials:

Fill: The surficial fill layer varies in thickness from approximately 1 to 7 feet and consists primarily of loose to medium dense, silty sand, silty sandy gravel, and sandy silt.

Volcanic Cinders: Cinder sands underlie the surficial fill layer from southeast of Mauna Kea Street through the remainder of the alternative subway alignment. Volcanic cinders generally consist of black to dark brown, poorly graded, medium to coarse-grained volcanic cinder sand that varies in thickness between 1 and 5 feet, except in the pre-existing topographic depressions where the cinder sand is up to 10 feet thick. Occasionally, the cinders contains silt and clayey silt. The cinder sands in this section are generally loose to very loose.

Reef Deposits: Between Kekaulike Street and Nuuanu Avenue, the surficial deposits of fill and cinders are underlain by thick coral reef deposits. The coral reef deposits vary in thickness from approximately 35 feet to 40 feet to a depth of approximately 45 feet below existing ground surface. In this portion of the alignment, the reef deposits consist primarily of some Type II coral, and mostly light brown or tan silty sand and coralline gravel. Locally off-white to brown clayey silt occurs as the matrix or as local lenses within the reef deposits. The coralline sand and gravel are expected to be variably cemented and uncemented layers, zones, and pockets of sand and gravel. In this portion of the alignment, the top 2 to 4 feet of the reef deposit appeared to be generally cemented, which produced relatively higher SPT blow counts and drill auger or roller bit grinding and chattering.

Standard Penetration Test (SPT) "N" values for the coralline sands and gravels generally range between 7 and 81 blows per foot. The occasional high SPT blow counts were obtained in locally cemented areas or where the sampler encountered a hard obstruction of cobble-sized coral chunks in the reef matrix.

East of Smith Street, an approximately 15-foot thick layer of tan, poorly graded, loose-to-medium dense silty fine sand (Beach Deposit) was encountered by Boring 10. This layer of generally uncemented sand appeared to extend and dip eastward to Alakea Street. Standard Penetration Test "N" values ranged from 7 to 27 blows per foot. In one boring (No. 10) the beach sand contained cemented gravel-size fragments.

Alluvial Deposits: All the three borings (Borings 10, 11 and 12) drilled along this section of the subway alignment encountered alluvial deposits beneath the coral reef. In general, the alluvial deposits consist of sand, silty sand, and silty gravelly sand interbedded with sandy and clayey silt, and zones of rounded to subrounded hard basaltic gravel, cobbles, and boulders. Gravel lenses are present in the alluvial deposits.

Standard Penetration Tests carried out in the alluvial sand, gravel and silt show "N" values ranged from 11 to over 50 blows per foot. The alluvial sands and silty sands are generally medium dense to very dense, uncemented to locally weakly cemented. The alluvial sandy silt and clayey silt have consistencies ranging from locally medium stiff to hard. Samples of hard bouldery clayey silt obtained from a 4- to 20-foot-thick layer of alluvial silt were fissured. This fissured clayey silt layer was encountered about 50 feet to 75 feet below existing ground surface.

Lava Flows: Exploratory borings drilled for the Mauna Kea parking structure encountered basaltic rock at a depth of approximately 110 to 115 feet below the existing ground surface, about 100 feet seaward of the proposed subway alignment. These basaltic rocks are believed to be part of the basaltic formation that occurred westward through to beneath the Ewa portal.

4.2.3 King/Bethel Station

The proposed King/Bethel Station is located between Nuuanu Street and Fort Street Mall, beneath South King Street. It is anticipated that the station will be located just west of the existing Satellite City Hall below South King Street and Fort Street Mall.

Boring 9 was drilled just upslope of the central portion of the proposed station area. Borings 8 and 10 were located about 130 feet to 100 feet, respectively, east and west of the proposed station area.

At the site of the proposed King/Bethel underground station, the thin surficial fill (3- to 5-feet-thick) and loose cinder sand (2 to 4 feet thick) layers are underlain by approximately 32 to 40 feet of reef deposits. Beneath the reef deposits, the borings encountered a 12- to 15-foot thick layer of loose beach sand deposit. Alluvial sand and silt were present beneath the reef and beach deposits. The exploratory borings indicated that the contact between the reef and alluvial deposits appeared to slope southward from about 48 feet below existing ground surface near Nuuanu Avenue to a depth of about 63 feet near Fort Street Mall.

During the field exploration, groundwater was encountered in the reef deposits approximately 18 to 20 feet below the existing ground surface, approximately 40 feet above the invert of the proposed subway station. The geological units encountered at this location includes the following materials:

Fill: The surficial 1- to 5-foot-thick fill layer encountered by the borings generally consists of medium dense to dense silty sandy gravel. The lower portion of the fill in Boring 8 contains cobbles.

Volcanic Cinders: Black cinder sands underlie the surficial fill layer. The cinders consist primarily of a poorly graded, medium- to coarse-grained, dense volcanic sands grains.

Reef deposits: The proposed King/Bethel Station area, reef deposits were encountered approximately 5- to 8-foot below the existing ground surface. The deposits consist of cemented moderately hard to hard Type I and II coral ledges and very loose to cemented coralline sand and gravel. The borings encountered Type I and II corals mainly in the upper 10 to 20 feet of the reef deposit. Where uncemented, the tan coralline silty sand, silty gravel and sandy gravel deposits are generally loose to medium dense, with SPT "N" values mostly in the range of 7 to 15 blows per foot. Higher "N" values (55 blows per foot) were obtained locally, where cemented sandy gravel were encountered.

Beach Deposit: A 10- to 15-foot-thick layer of beach sands was encountered approximately 43 to 49 feet below existing ground surface. The beach deposit contains tan silty sand and clean, poorly graded fine sand, with some shells and coral fragments. The SPT "N" values ranged from 9 to 19 blows per foot and indicates that the in-place density ranges from loose to medium dense.

Alluvial Deposits: The exploratory borings encountered in the alluvial deposits primarily brown to dark brown silty sand, sand, and gravelly or pebbly sand from approximately 46 to 63 feet below the existing ground surface to the bottom of the holes (101.5 feet). Occasional pockets and local thin layers (3 to 6 feet thick) of brown stiff clayey silt and tan coralline sand and gravel were found intercalated with the river deposits. Hard basaltic cobbles and boulders were encountered within the alluvial material primarily near the bottom of the borings. Cemented nodules were present in two of the three station borings.

The lateral extent of the alluvial sand and clayey to sandy silt is highly variable and is expected to change substantially within short horizontal and vertical distance. In general, the deposit dips to the south and should not be present in the tunnel profile south of the King/Bethel Station.

Standard Penetration Test "N" values of the silty sand and gravelly sand deposits ranged from 1 to 27 blows per foot, indicating very loose to medium dense sands; the clayey silt and sandy silt "N" values ranged from 15 to 27 blows per foot, indicating stiff to very stiff soils.

4.2.4 King/Bethel Station to King/Punchbowl Station

Five exploratory borings (Borings 3, 4, 5, 6, and 8) were drilled in this approximately 2,300-linear-foot section of the King Street Subway alignment.

The borings encountered primarily thin (1- to 5-foot thick) fill and cinders (1- to 8-foot thick) layers overlying a very thick (40-foot to more than 70-foot-thick) formation of reef deposits. The beach deposits described in Section 4.2.3 appeared to dip southward, to below the proposed tunnel invert, south of Boring 8. Beneath the reef and beach deposits, the top of the alluvium continues to dip north to south, from about 63 feet in depth in the Fort Street Mall area (Boring 8) to about 85 feet in depth (Boring 5) in the Richards Street area. Between Fort Street Mall and Richards Street, alluvial deposits were encountered to the drilled depths of approximately 100 feet.

Based on the preliminary borings, the eastern extent of the alluvial sequence was terminated between Richards Street and Mililani Street. Moreover, these alluvial deposits end abruptly against the wall of a major erosional channel that was also encountered in the Alakea Street area and identified in the Hotel Street Subway geotechnical study. The eastern flank of the channel contained basaltic lava flow(s). It is not known whether the lava-flow encountered in the western portion of the project area is the same formation beneath Mililani Street.

The proposed tunnel construction, at depths of approximately 30 to 50 feet is likely to encounter primarily reef deposits along this section of the alignment. In general, the groundwater was encountered at approximately 10 to 13 feet below the existing ground level at the time of the field exploration (January 1992). The following geological units were encountered:

Fill: Along this section of the alignment, the surficial material consists of a 1 to 5 feet thick layer of fill. The fill layer contained loose to medium dense, silty sand, and silty sandy gravel. Hard cobbles were encountered in Boring 8.

Volcanic Cinders: Cinder sands of variable thickness underlie the fill materials. The volcanic cinders consist primarily of a black, poorly graded, medium to coarse sand and silty sand. This deposit varies in thickness from approximately 1 to 8 feet. The cinders are generally in very loose to loose, but locally, the cinders may be fused and a 3-inch-diameter drive sampler was obstructed near the top of the layer in Boring 6.

Reef Deposits: The thickness of the reef deposits increases from about 40 feet near Fort Street Mall to about 70 feet or more near the proposed King/Punchbowl Station. The reef deposits are expected to include very loose to cemented tan, fine to medium sand and loose to cemented coralline gravel to silty sandy gravel, local lenses of stiff brown clayey silt, and from weakly to strongly cemented Type I and II coral. Standard Penetration Test "N" values in the coralline sands and gravels ranged from 8 to 55 blows per foot. Cored samples of cemented coral may have unconfined compressive strength that range near zero (friable weak rock) to over 4,000 psi.

The lateral and vertical extent of the coralline sand, gravel, weakly cemented coralline debris to hard, widely jointed coral reef is expected to be very complex and can vary substantially over very short distances, in both horizontal and vertical directions.

Approximately 13 to 30 feet of continuously cored Type I and II coral was encountered in Borings 3, 4 and 5, between Richards and Punchbowl streets. These relatively thick, well-cemented coral ledges appeared to be part of a major reef structure underlying the area.

Alluvial Deposits: The four borings drilled in this section of the alignment encountered alluvial deposits at depths of approximately 63 feet at the Fort Street Mall area, to approximately 86 feet beneath Richards Street. In general, the alluvial deposits consist primarily of brown to dark brown sandy silt, sand, gravelly sand, sandy silty gravel and lenses or layers of reddish brown clayey silt.

Standard Penetration Test "N" values in alluvial sandy silt and clayey silt ranged from 6 to 21 blows per foot, indicating medium-stiff to stiff soils; and 3 to 28 blows per foot for very loose to dense alluvial sand and gravel.

Hard cobbles and boulders were encountered in some of the borings, obstructing sampler penetration.

Lava Flows: Beneath Mililani Street, the alluvial deposits appeared to be deposited against, and over basaltic lava flow(s) at a depth of approximately 65 feet below existing ground surface. The basalt in this area is generally dark gray, dense, contains some vesicles, closely to moderately fractured, slightly weathered to unweathered, hard to very hard. This basaltic rock unit is at least 16 feet thick at the boring location.

4.2.5 King/Punchbowl Station

Due to restricted access and underground utilities, only one boring (Boring 3) was drilled in the vicinity of the proposed King/Punchbowl Station.

The boring showed approximately 8 feet of thick volcanic cinder at a depth of approximately 77 feet to 83 feet above a very thick sequence of reef deposits. A layer of hard volcanic tuff was encountered within the thick sequence of reef deposits.

The widely spaced adjacent borings (Borings 1 and 4) in conjunction with Boring 3 indicate that the proposed subway station would be excavated through hard Type I and II corals down to very loose to variably cemented coralline sand and gravel. The bottom of the proposed station may be founded on loose to medium dense fine to medium sand. The groundwater level was encountered at approximately 12 feet below the existing ground surface during field exploration, approximately 40 to 50 feet above the invert of the proposed station. The borings indicated that geological units encountered along this section of the alignment include the following materials:

Volcanic Cinders: Approximately 8 feet of volcanic cinder were encountered beneath the concrete sidewalk slab at Boring 3. The cinders consist primarily of dark brown to black, fine to medium-grained, very loose volcanic sand.

Reef Deposits: The boring encountered a 13-foot-thick ledge of off-white, hard, Type I coral beneath the cinder deposit. It is not known whether this upper coralline ledge may thicken toward the west where Boring 4 encountered an approximately 35-foot-thick layer of Type I coral. The thickness of this coralline ledge may decrease towards the east where Boring 1 encountered uncemented to locally cemented coralline sand and gravel.

Beneath the upper coral ledge, the reef deposits consist primarily of off-white to tan uncemented to locally cemented coralline sand and gravel with trace of silt and shells, to a depth of approximately 56 feet below the existing ground surface. Standard Penetration Test "N" values ranged from 6 to 56, indicating loose to very dense conditions. Due to the low silt content noticed from examination of soil samples, the reef formation in this general vicinity is expected to be very porous.

An approximately 14-foot-thick, medium-dense (SPT "N" = 18 blows per foot), fine to medium sand was encountered about 57 to 69 feet below existing ground surface. This sand unit contains locally cemented zones.

Below this fine sand layer and the volcanic tuff unit described below, the reef deposits consist primarily of tan, loose to cemented coralline sand and gravel, with some silt in the matrix.

Volcanic Tuff: Volcanic tuff deposit was encountered at approximately 75 to 81 feet below the existing ground surface. A 1-foot layer of fused cinder sand was found to cap the finer grained, moderately to closely fractured, moderately hard to hard volcanic tuff.

Petrographic examination of a sample of volcanic tuff obtained from a boring drilled in the Municipal Building area during the Hotel Street Subway Geotechnical Study indicated that the tuff is probably an altered, poorly sorted pumice tuff. It was probably an airfall or slightly reworked airfall deposit of an explosive Honolulu Series eruption.

4.2.6 King/Punchbowl Station to Kapiolani Boulevard/South Street

Two borings (Borings 1 and 2) were drilled along this approximately 1000-linear-foot section of the subway alignment. These borings encountered a thin mantle of fill and volcanic cinders over a thick sequence of reef deposits. Within this thick reef sequence, a layer of volcanic tuff was encountered approximately 60 to 68 feet below existing ground surface. This tuff layer is believed to be the same tuff unit that was encountered in the general vicinity of the Punchbowl Street and Kapiolani Boulevard areas.

Depending on the depth of the proposed subway invert, the subway tunnel is likely to encounter primarily uncemented and cemented reef deposits. The volcanic tuff is expected to occur very close to the proposed tunnel invert. Depending on the preexisting topography at the time the tuff was deposited, the occurrence of the hard volcanic tuff may vary within a short distance.

Groundwater was encountered at approximately 10 feet below the existing ground surface during field exploration. The exploratory borings encountered the following geological units along the subway alignment:

Fill: Along this section of the alignment, the surficial fill material is very thin, about 1 to 2 feet thick, and consists primarily of clayey silt to silty sandy gravel.

Volcanic Cinders: In general, volcanic cinders approximately 4 to 5 feet thick underlie the surficial fill. Boring 2 also encountered an approximately 5-foot-thick layer of loose, fine sand between the surficial fill and underlying cinders. The cinders primarily consist of black, poorly graded, medium to coarse grained, very loose to loose volcanic sand grains.

Reef Deposits: Samples of reef deposits obtained from the borings ranged from uncemented to cemented gravel to cobble-sized coralline debris, sand and gravel, and cemented sandstones to approximately 2- to 4-foot thick lenses of sandy silt and silty sand. However, the reef deposits in this general area appear to consist predominately of gravel to cobble sized coral chunks with only traces of silt in the debris matrix. Thus, a substantial amount of void space exists within this thick sequence of reef deposits.

Standard Penetration Tests "N" values ranged from 6 to 56 blows per foot, indicating very loose to dense soil conditions. The higher blow counts may be a result of local recementation of the coralline debris, or obstruction of sampler penetration by cobble to boulder sized coral chunks.

Volcanic Tuff: An approximately 10-foot-thick layer of volcanic tuff was encountered interbeded with the reef deposits. The tuff is generally brown to greenish blue, thinly bedded, moderately hard to hard, close to moderately fractured, locally containing friable zones and cobble-sized coral inclusions. In Boring 2, the top 2 feet of the tuff also appeared altered or weathered, consisting of fused medium to coarse volcanic sand grains.

During the Hotel Street Subway geotechnical study, a sample of volcanic tuff obtained from a boring drilled in the Municipal Building area yielded an unconfined compressive of 1550 psi.

4.2.7 Kapiolani Boulevard/South Street to Waimanu Street

This section of the King Street subway alignment merged with that of the Hotel Street Subway alignment. New exploratory borings were not located in this section of the subway alignment. Four exploratory borings (HB-27 through HB-30) were drilled along this 1600 linear feet section of the proposed subway alignment during the Hotel Street Subway geotechnical study.

The drilled holes encountered an approximately 85-foot-deep erosional channel, approximately between Stations 750+00 to 753+00. The channel was infilled by alluvial and volcano cinders. Other available subsurface information in this general vicinity indicates that this buried channel may meander somewhat along Kapiolani Boulevard. It appears that a second, shallower, cinder infilled channel, about 30 feet deep (which was encountered by boring drilled seaward of Kapiolani Boulevard for another project), may occur approximately 400 feet east of the major channel.

East of the major buried channel, the borings primarily encountered thin layers of near-surface compressible lagoonal silts, thick reef deposits, and relatively thin layers and lenses of alluvial silts and local tuff interbeds.

Groundwater was encountered approximately 6 feet below existing ground surface at the time of the Hotel Street Subway field exploration.

The available subsurface information indicated that the Koko Head (east) portal and U-wall will be constructed through an approximately 3- to 7-foot-thick surficial fill layer, approximately 10 to 12 feet of soft, highly compressible lagoonal silt deposits, thick reef deposits containing highly permeable coralline sand and gravel, with some locally well-cemented zones, and alluvial silt and clay interbeds. The geology within this segment of the alignment consists of the following materials:

Fill: The surficial material consists of a 4 to 5 feet thick of fill. The fill materials are primarily sandy gravels, fine sands and sandy silts.

Volcanic Cinders: Cinder sands appear to underlie the surficial fill layer, except in the general area where Boring HB-28 is located. As mentioned above, a major buried erosional channel exists below and east of the junction between Kapiolani Boulevard and South King Street. The exact lateral extent of this infilled channel is not known. Within the channel, cinder sand was encountered to a depth of about 36 feet below existing ground surface. Near the base of the cinder unit, approximately 16 feet of hard, cemented or fused cinder sand was cored by Boring HB-27. The cinder sand encountered at the upper portion of the infilled channel appeared to be loose (SPT "N" = 6 blows per foot).

Southeast of the buried channels, approximately 2 to 10 feet thick of loose to medium-dense volcanic cinders were deposited over a thick sequence of reef deposits and local lenses of alluvial silts.

Alluvial Deposits: Approximately 54 feet of alluvial silts and clays were encountered at the bottom 36 to 83 feet of the major buried channel. The alluvium generally consists of stiff, to very stiff brown clayey silt; clayey and sandy silt; and sandy clay. Standard Penetration Tests conducted in the alluvial silts indicated "N" values ranged from 24 to 40 blows per foot.

Southeast of the buried channels, 3 to 12 feet thick stiff alluvial silt (SPT "N" = 27 to 28) layers were found to occur within the thick reef sequence.

Reef Deposits: Coralline deposits encountered in this section of the alignment consist primarily of Type I and II corals and loose to cemented coralline gravels and silty sands. The thickness and lateral extent of these materials are highly variable, and it is not possible to correlate accurately between boreholes. Shallow, local ledges (9 to 11 feet thick) of tan to off-white, generally moderately cemented, highly jointed Type I coral was encountered in Borings HB-28 and HB-29, at depths of about 15 feet below existing ground surface. Type II corals consisting of recemented, moderately to closely fractured, medium soft to soft material (approximately 14 feet thick) were encountered in Borings HB-28 and HB-29, at depths between 35 feet to 50 feet.

Standard Penetration Test "N" values obtained in generally uncemented to locally cemented coralline silty sands and gravels ranged from 6 to 46 blows per foot, indicating very loose to dense or cemented conditions.

4.3 Hydrogeological Overview

The hydrogeological characteristics of the geological units along the proposed tunnel alignment make up a complex stratigraphic sequence which is variable both horizontally and vertically. In this general area, groundwater is predominantly recharged from the Honolulu Harbor, Nuuanu Stream, and precipitation falling on the uphill areas northeast of the alternative alignment. The position of the groundwater table will also be influenced by tidal fluctuations and construction activities, such as dewatering.

In-hole falling head and water pressure testing (packer test, performed during the Hotel Street Subway geotechnical study) are used to provide an index, that is, the relative order-of-magnitude of the permeability of the geological material being tested. The tests were of short duration, generally no longer than 1 hour per isolated test zone. These are preliminary tests which provide a basis for deciding whether more detailed and longer-term testing, such as pump tests are required.

Based on the results of this study, we recommend that appropriate detailed investigations and pump tests should be conducted for each of the proposed portals and the King/Bethel and King/Punchbowl stations, if construction dewatering is required.

4.3.1 Kaaahi Street to Kekaulike Street

During the field explorations, groundwater was encountered within the organic deposits, alluvial deposits, and the basaltic lava flow(s). The borings indicated that groundwater level occurred approximately at or near mean sea level, at approximately 0.5- to –3-foot elevations.

Packer tests carried out during the Hotel Street Subway geotechnical study indicated that organic sandy silts and clays horizons tested yielded permeability values of $2x10^{-3}$cm/sec. and 6.9×10^{-4}cm/sec. (Borings HB-2 and HB-5). Falling head test conducted by this study in Boring 7 in organic sandy silts yielded permeability values of 4.9×10^{-5},indicate the variable permeability characteristics of the highly compressible organic deposits.

Packer tests conducted in basaltic rocks during the Hotel Street Subway geotechnical study indicated that permeability values range from approximately 1.1×10^{-3}cm/sec. to 6×10^{-5} cm/sec. in highly fracture to slightly fracture rock mass.

Falling head tests conducted in Boring 7, in the alluvial silty sand and boulder zones, yielded permeability values of 2.0×10^{-3}cm/sec., indicating the presence of highly permeable zones within the alluvial deposits.

Due to the permeable nature of the organic silts, alluvial deposits, and basaltic lava flows in this general area, these deposits are probably hydrogeologically connected with the extensive reef and alluvium aquifer located to the east of Kekaulike Street.

The highly compressive organic deposits will undergo extensive consolidation settlements upon drawdown of the water or depressurization of the acquifer. Conventional construction dewatering should not be permitted.

4.3.2 Kekaulike Street to Richards Street

The exploratory borings indicated that a porous reef aquifer predominates the top 40 to 85 feet of this portion of the alternative alignment. Due to the complex interbedding of river gravels and cobbles layers, river sands, sandy silts, and clayey silt lenses and layers, a highly variable aquifer/aquiclude systems appear to exist within the underlying alluvial deposits.

Based on the six borings drilled along this portion of King Street subway alignment, groundwater was encountered approximately at or near mean sea level, at approximately 9 to 19 feet below existing ground surface.

Earlier packer tests conducted in reef deposits along the downtown portion of Hotel Street indicated permeabilities values of 1.2×10^{-3} to 1.7×10^{-5} cm/sec., with the porous coralline sand and gravel at the higher end of the range. Coralline deposits containing some silt in the matrix, and well cemented coral ledges yielded lower permeability values (5×10^{-4} and 1.7×10^{-5} cm/sec.). Falling head tests conducted for this study in primarily silty sandy coralline gravel and Type I coral ledges yield permeability values of 2.0×10^{-4} and 1.2×10^{-3} cm/sec. (Borings 8 and 10).

Falling head permeability tests conducted in alluvial clayey silts yield permeability values of 7.2×10^{-6} cm/sec., test conducted in alluvial silty sand yielded permeability values of 1.7×10^{-5} cm/sec. and test conducted in alluvial sand and silty cobble layers yielded permeability values of 2.8×10^{-3} cm/sec. These data appear to confirm permeability values of 1.4×10^{-3} cm/sec. and 5.9×10^{-4} cm/sec. obtained from earlier packer tests in the downtown portion of the Hotel Street Subway alignment.

These test data indicated that the alluvial deposits contains highly permeable deposits and should not be relied upon as dewatering cut-offs without further investigations and pump tests.

4.3.3 Richards Street to Waimanu Street

This portion of the subway alignment consists primarily of very thick sequences of reef deposits. The coralline sand, gravel, and cobble debris appeared to contain only traces of silt in many borehole samples and is known to be extremely permeable, as indicated by the pump test conducted near the Municipal Building during the Hotel Street Subway study. This earlier pump test indicated that the volcanic tuff layer and cinders and alluvium infilled buried channel appeared to have no significant effect on the high permeability of this aquifer. Aquifer transmissivity of 1,500,000 gpd per foot was obtained during the pump test.

While falling head permeability tests conducted in the reef deposits yielded permeability values of 7.3×10^{-3} to 4.5×10^{-4} cm/sec., confirming results obtained by packer tests in coralline sands and Type I and II coral reefs (permeability values of 2.1×10^{-3} cm/sec. to 4.3×10^{-3} cm/sec.) during the Hotel Street Subway geotechnical study. Pumping tests usually yield higher and more accurate values due to opening or clearing of void space and removal of fines around the pump well, by well development procedures, and prolonged pumping.

4.4 Tunneling Ground Conditions and Constraints

Organic and Lagoonal Deposits: The organic and lagoonal deposits can be expected to squeeze and flow into any unsupported excavation. Loss of water and materials into the face and through lining could cause settlement problems in overlying and adjacent structures and utilities. Without appropriate ground improvement, a combination of the effects of buoyancy and potential consolidation settlement due to equipment and tunneling loadings could make accurate alignment control extremely difficult, if not impossible. Tunneling methods involving the use and circulation of slurries or earth pressure balance muds, may be adversely affected by excessive loss of the slurries due to potential displacement of the soft lagoonal deposits by the denser slurry.

Volcanic Cinders: Well-cemented cinders should behave like a weak rock and neither flow not run into the tunnel. Saturated uncemented cinders will flow into any unsupported underground excavations.

Reef Deposits: Flowing conditions are expected in the saturated, uncemented sand and gravel in any unsupported excavation. Cemented zones or layers will cause obstructions and make it difficult to control the ground. Tunneling or other underground excavation using compressed air will not be feasible in the porous and highly variable reef formation due to potential excessive air loss. Substantial cement and chemical grout injection around Bethel/King and Punchbowl/ King stations is anticipated to allow egress or ingress of a TBM. Due to the porous nature of the reef formations, and potential detrimental settlement associated with dewatering, conventional dewatering along the subway alignment for underground or subway construction may not be technically or economically feasible.

Beach/Alluvial Deposits: Flowing conditions are expected in saturated uncemented sand and gravel deposits, in any unsupported excavations. Hard cobbles and boulders form obstructions and make it difficult to control the ground during tunneling. Lost ground is expected when tunneling in stiff or hard materials found along the invert and through the loose sand that may be encountered along the arch and crown. There is also a potential for heavy water inflows from the porous zones and layers exhibited by these deposits.

4.5 Conclusion

The geology encountered along the King Street Subway alignment is mixed and highly complex when appraised from the perspective of underground construction. The major geological constituents include lava flows, alluvial deposits, organic deposits, lagoonal deposits, reef deposits, beach deposits, cinder sands, and man-made fill. This environment is further complicated by the local groundwater elevation, which is approximately 4 to 22 feet below the ground surface. These conditions are major factors influencing the proposed method of subway construction, and the final design characteristics of the permanent structure.

With the exception of basalt and some volcanic tuff, all of the materials are considered to be relatively soft from a mined-tunnel standpoint. The Honolulu Series basalts are extraordinarily hard and may reach unconfined compressive strengths of approximately 25,000 psi. Tunneling and excavation equipment is most efficiently and effectively utilized when it is operated in a homogeneous environment. An analysis of the geologic profile revealed that the extremely hard basalts were found at minimum depths of approximately 50 to 100 feet. The elevation of the basalt layer was considered a constraint when the vertical profile of the proposed tunnels was established. By avoiding basalt formations, mixed-faced tunneling would be circumvented thereby reducing construction difficulties and related construction costs. However, actual below-grade conditions can never be predicted with exact precision. The degree of certainty corresponds only to the extent of the geotechnical exploration program.

The organic deposits found near the Nuuanu Stream are soft and highly compressible and some form of ground improvement technique will be required, regardless of the selected construction method. Ground improvement techniques may include of jet grouting or chemical grouting; both serve to strengthen the highly compressible soils.

Ground displacement, settlement, and deflections are all of concern, particularly in soft soils along the developed King Street alignment. It is imperative that the design and construction carefully consider and monitor potential ground displacements so as to mitigate the possibility of inflicting structural damage on adjacent sensitive buildings. As stated earlier, the geology is complex consisting of a nonhomogeneous mix of materials. The corals are interwoven with alluvial clays, silts, and sandy gravels. The disjointed nature of this material make the magnitude and profiles of any settlement troughs very difficult to predict.

The mitigation measures entail detailed additional geotechnical engineering investigations, extensive geotechnical testing and analysis, utilization of construction techniques that characteristically minimize ground displacement, and the implementation of a comprehensive geotechnical monitoring program. These measures are applicable to mined and cut-and-cover construction methods, although each have particular advantages and disadvantages that are described in detail in Sections 5 and 6.

The groundwater elevation will be an additional concern during the construction period and service life of the transit facility. With the exception of isolated segments of vent and portal structures, the entire subway will be located below the water table. This could have a severe impact on construction in light of the existing soil conditions. A high percentage of the soil is quite pervious; therefore high volumes of groundwater inflow can be expected along excavated or open surfaces that extend below the water table. Additionally, if water is permitted to flow freely into an excavation or mined tunnel, it is likely to carry away fines or small particles of soil that constitute the natural state of the ground. If a significant amount of fines were washed away by groundwater inflow, the supporting capacity of the immediate ground would be lost. The consequence could be unacceptable building deflections or the failure of existing foundations. Obviously, this scenario must be avoided and a design solution will be selected that precludes the potential of foundation failures. Solutions include, but are not limited to, ground freezing, groundwater lowering, shield machines, and cutoff walls. An evaluation of the soil characteristics detailed within Section 4 of this study suggests that groundwater inflow can best be controlled by a slurry concrete diaphragm wall for cut-and-cover construction, and that an earth pressure balance machine would be most suitable for any proposed mining operations.

5.0 SUBWAY STRUCTURES

5.1 Introduction

The proposed King Street Subway would be composed of three distinct structural configurations identified as the line, station and portal structures.

The line structure refers to the running tunnels that house the standard guideway configuration, allowing the transit vehicles to pass from station to station. The design of a running tunnel or line structure usually emphasizes optimization of the cross section to efficiently accommodate only the vehicle clearance envelope, an emergency walkway, and any system related equipment.

The subway station structure is an underground facility designed to house all of the components associated with passenger transfers to and from the transit vehicle. The station components typically include entrances, vertical circulation elements, ticket vending areas or concourses, platforms, signage, lighting, and ventilation systems. Station structures also house the guideway and associated system electrical and communication equipment. The design of station structures is usually controlled by the station site as most subway stations are located in high density urban areas. The station configuration and selected construction technique generally considers right-of-way restrictions, protection of existing buildings, pedestrian and vehicular traffic disruption, soil properties, water table characteristics, and the impact to existing underground utilities.

Portal structures provide guideway transitions between the aerial and underground guideway alignments. The portal is designed principally to stabilize and retain the surrounding earth at the transition zones between above and below grade transit facility. The design of a subway portal must also address environmental criteria related to visual and noise impacts.

5.2 Line Structures

In traditional subway construction, two distinct types of tunnels are typically considered; cut-and-cover tunnels and bored tunnels. The two types of tunnels are differentiated by the construction method involved. Both methods have various advantages and disadvantages depending upon the particular conditions encountered. This section will provide an overview of each method and discuss their applicability for the King Street Subway.

5.2.1 Cut-and-Cover Tunnels

Cut-and-cover tunneling is the traditional method of underground construction and as such is utilized daily, albeit on a small scale, for the construction of underground utilities. It is a relatively straightforward method, familiar to many general contractors, utilizing readily available technology.

One of the greatest advantages of cut-and-cover tunneling over bored tunneling is adaptability. The designer has the ability to vary the tunnel configuration along the line as necessary to meet specific operational requirements. The tunnel can be constructed as a single cell or with multiple cells, narrow or wide, horizontally or vertically oriented as required.

In contrast, by nature of the construction process, a bored tunnel's configuration cannot be varied along the alignment. The configuration is established by the characteristics of the selected tunnel boring machine. The boring machine is generally used throughout the length of the drive, and as a result, the tunnel cross section is a constant. Therefore, at several locations along any subway alignment, such as at special trackwork areas (turnouts, crossovers, switches, and pocket tracks), it will be necessary to use the cut-and-cover tunneling method or a hand-mined tunneling method. Hand mining refers to relatively labor intensive tunnel excavation that utilizes a combination of manual labor and power-operated excavation equipment.

Cut-and-cover structures can readily transition between different configurations. Typical line tunnels could include single, double, or multiple cell-box structures. They are also appropriately used in areas of the alignment where dual guideway centerlines are in such close proximity that twin bore tunnels become geotechnically impractical or geometrically impossible.

A Typical configuration for cut-and-cover subway tunnels is illustrated in Sketch 5.1, which depicts a standard parallel track configuration. This cross section is advantageous due to attributes that include; relatively shallow excavation requirements, reduced excavation support, and enhanced flexibility for crossovers, special trackwork and cross passages.

For an alignment with sufficient right-of-way, such as along King Street, the standard parallel track, cut-and-cover box structure would be a suitable configuration for the permanent facility. However, the cut-and-cover configuration would exhibit serious deficiencies when evaluated in terms of construction impacts, which are discussed in Section 6.

5.2.2 Mined Tunnels

The construction and relative success of tunneling operations is very much a function of surrounding geology and soil conditions. Moreover, the general feasibility and overall design of a mined tunnel is substantially a direct correlation with the geologic parameters. Expected ground behavior and tunneling conditions are key input parameters for the design and construction of underground openings.

Numerous mining methods have been devised to cope with a multitude of tunneling environments. Mined tunnels have been constructed in materials ranging from extremely hard rock to very soft clays and silt, all with varying levels of hydrostatic head, and each with unique geological profiles requiring unique design solutions. The analysis and design process generally entails evaluation of ground deformation, surface settlement, water infiltration, and support mechanisms for initial and primary tunneling conditions. Tunnel construction requires constant monitoring of the surroundings to verify that the soil response is within the forecasted design limits. Any perceptible deviation requires immediate analysis followed by a corresponding modification to the construction technique to ensure the stability of the tunnel opening and/or protect existing buildings.

Mined tunnels are attractive because they are unobtrusive to surface activities during construction and service operation. They generally function unnoticed for decades and require a minimal amount of maintenance effort. In addition, the capital cost of a mined tunnel may be a significant advantage over other construction techniques, particularly when excavations are deep or surface disruption becomes prohibitive.

5.2.2.1 *Tunneling Environments*

As previously discussed, the tunneling environment is instrumental in determining construction technique and final tunnel structure design. The following discussion provides a brief overview of tunneling environments likely to be encountered along King Street.

Rock

Tunneling in full face rock is not anticipated along the King Street Subway alignment. When the vertical profile of the subway alignment was established, a conscientious attempt was made to avoid the lava flows (basalt). A few local outcrops of hard basalt might be encountered at depth, near the Nuuanu Stream and Mililani Street. These are not typical, and would not govern the selection of a TBM. Hard basalt, if encountered in isolated locations, could be excavated by predetermined methods such as hand mining through the face of a boring machine. Some volcanic ash (tuff) and cemented coral will be present and the selected TBM should be designed to excavate through these materials.

Mixed-Face

Mixed-face tunneling is a condition where two or more types of ground are encountered simultaneously in the tunnel face, which have such different properties and behavior that a soft ground tunneling operation might encounter hard rock; or a rock tunnel crew might encounter soft ground. In mixed-face tunneling the unexpected change of materials and contrast in the properties of the materials may make the initial equipment and personnel unusable, especially if the change is not anticipated.

For the purposes of this project, mixed-face conditions will refer to geologic zones of significant contrast, such as tunneling from a soft lagoon material into a partially basalt face, from lagoon material into hard coral, or from lagoon material into alluvial deposits, or vice versa. The King Street tunnel is likely to encounter these conditions, in addition to man-made obstructions such as tiebacks. Although it is feasible to obtain modern TBMs that have the capability to cope with mixed-face conditions, careful scrutiny and evaluation will be required prior to choosing an appropriate mining method for King Street underground project.

Soft Ground

Soft-ground tunneling applies basically to soils that will not be self-supporting for a significant length of time and that therefore must be supported as fast as it is tunneled. In general, soft-ground tunneling may advance by hand or TBM mining methods. A tunnel shield is commonly used in soft-ground conditions. It consists of a steel cylinder with overall dimensions equal to the tunnel bore and protect the men and mechanical equipment used to excavate the tunnel.

Only a relatively short length of the King Street Subway will encounter highly compressible organic soils and this material is located in the vicinity of the Nuuanu Stream. However, the selection of the mining technique must consider the characteristics of the entire alignment. Some type of shield will be needed to handle the expected range of ground conditions.

Soft Ground Below the Water Table

The problem of controlling water in underground openings during construction has been addressed in numerous ways over the years. In many cases, water flowing into rock excavations may not in itself produce a significant safety hazard to men or to the excavation, though it may slow the work and thus raise costs. In soft ground materials, however, the inflow of water could bring with it particles of the ground, cause piping, and thus erode or even collapse the excavation. In tunnels, the inflow of water and associated erosion of the ground can be extremely dangerous and it must be controlled.

Barriers to prevent water infiltration have been constructed of various grouts, slurry, frozen ground, and other materials. In recent years, several types of TBMs, designed specifically for tunneling below the water table, have been developed. These are referred to as slurry-shield and earth-pressure-balance machines. Slurry shield will not be suitable for this project because of the presence of boulders and rock. For the range of expected ground conditions, the only feasible method of underground construction is some type of Earth Pressure Balance TBM that is capable of cutting hard rock and controlling lost ground. Replacement grout should be considered in the reef deposits to protect structures and utilities.

The majority of the King Street Subway will be located beneath the water table.

5.2.2.2 *Tunnel Configurations*

A number of configurations are possible with mined tunnels, each possessing characteristics that are advantageous to a specific tunneling environment. In many cases the most pertinent problem is tunneling-induced surface settlement or ground displacement, particularly when it influences the foundations or support systems for existing structures. Ground lost into a tunnel during excavation causes the ground immediately above the tunnel to rearrange itself, and the rearrangement can migrate up to the ground surface at an angle which varies with the soil type. This creates a "settlement trough" that can distort and damage nearby structures. Even the best tunneling methods will result in approximately 2 percent "lost ground" (i.e., 102 percent of the theoretical volume has been in fact excavated).

Twin Circular Tunnels

A common configuration for subway tunnels is two identical tunnels placed side by side, as indicated in Sketch 5.2. These tunnels are typically excavated with TBMs and supported by segmental liners. Twin circular tunnels appear to be the most feasible solution for the King Street Subway.

Measurements have been made of ground movements and settlement in soft ground for a large number of such circular tunnels, above and below the water table. The first tunnel to pass a given point causes some initial settlement trough at the ground surface. The effect of the second tunnel being excavated later near the first is complex: the ground is once again rearranged. The "pillar width" or distance between the two tunnels is an important factor. Approximately speaking, for uncemented sands below the water table, the settlement trough at the ground surface may be estimated by extending a line 45 degrees upward from the tunnel springline. Thus, the settlement trough induced by a tunnel 40 feet below the surface would be about 40 feet wide on either side of the tunnel. Structures within the settlement trough might be subject to varying degrees of displacement and/or distress.

One of the key requirements of the King Street Subway construction will be control and reduction of ground losses because of the presence of surface structures and utilities. Tunneling methods that prevent ground loss and consider the use of replacement grout must be selected.

Single Circular Tunnel (Dual Track)

Sketch 5.3 depicts a large single circular tunnel with sufficient cross-sectional area to house both guideway tracks.

A single large tunnel has the advantage of simplifying some of the structural and geometric complexities associated with individually mined tunnels. Conversely, this tunnel section would require a greater total volume of excavation, additional and larger structural lining elements, potentially produce increased magnitudes of surface settlement, and typically necessitate a lower vertical profile.

Twin Horseshoe Tunnels

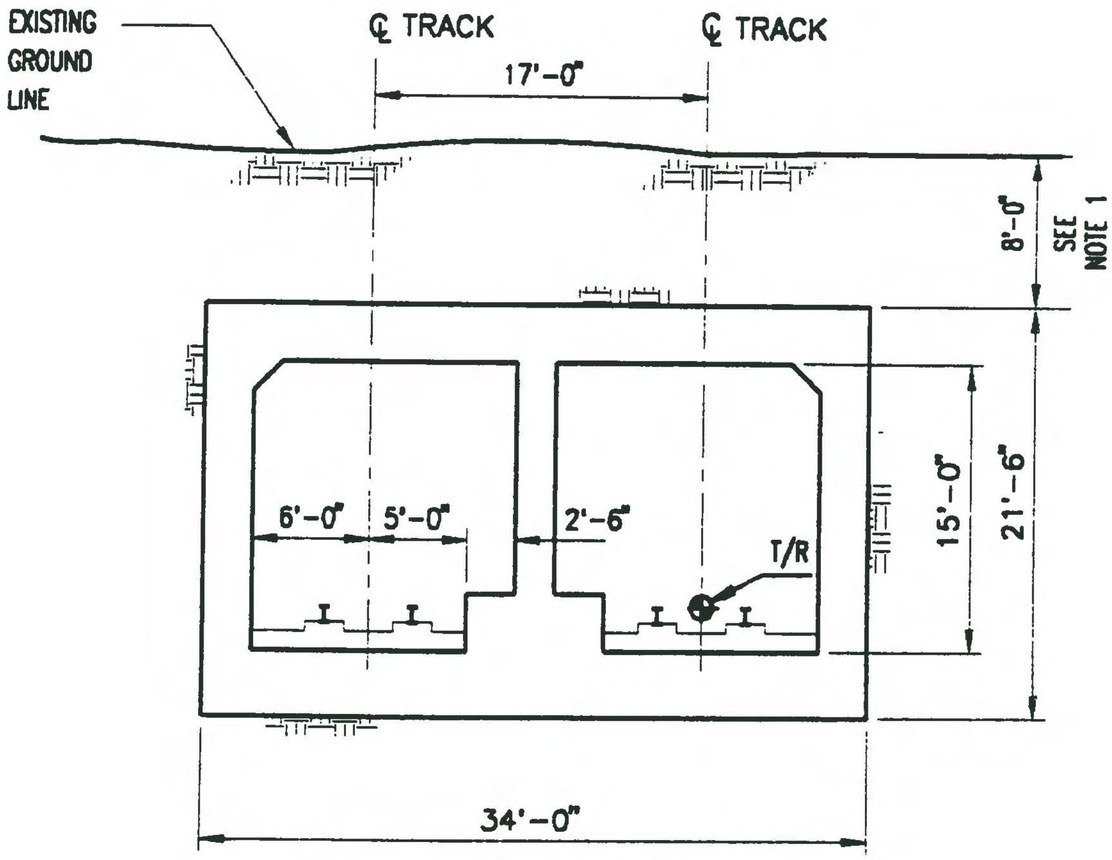
Sketch 5.4 illustrates twin horseshoe-shaped tunnels that are frequently used for subways constructed by NATM.

Ground displacement and settlement troughs would share characteristics similar to the TBM constructed, twin circular tunnels. The magnitude of settlement would correlate closely with both the selected construction sequence and the applied standards of construction quality. NATM does require a moderately dry ground surface to successfully apply shotcrete. The King Street Subway tunnels are well below the water table, and unless the groundwater inflow was stabilized, NATM would be impossible to construct.

Single Horseshoe Tunnel (Dual Track)

A single horseshoe tunnel, as shown in Sketch 5.5, could be constructed using NATM. This tunnel would have an advantage over the single circular tunnel because the NATM cross section could be customized to match the actual system space requirements thus minimizing the degree of over excavation.

The application of this configuration would be contingent upon overcoming the remaining disadvantage characteristic of the single large excavation as well as surmounting the groundwater problem associated with NATM construction.

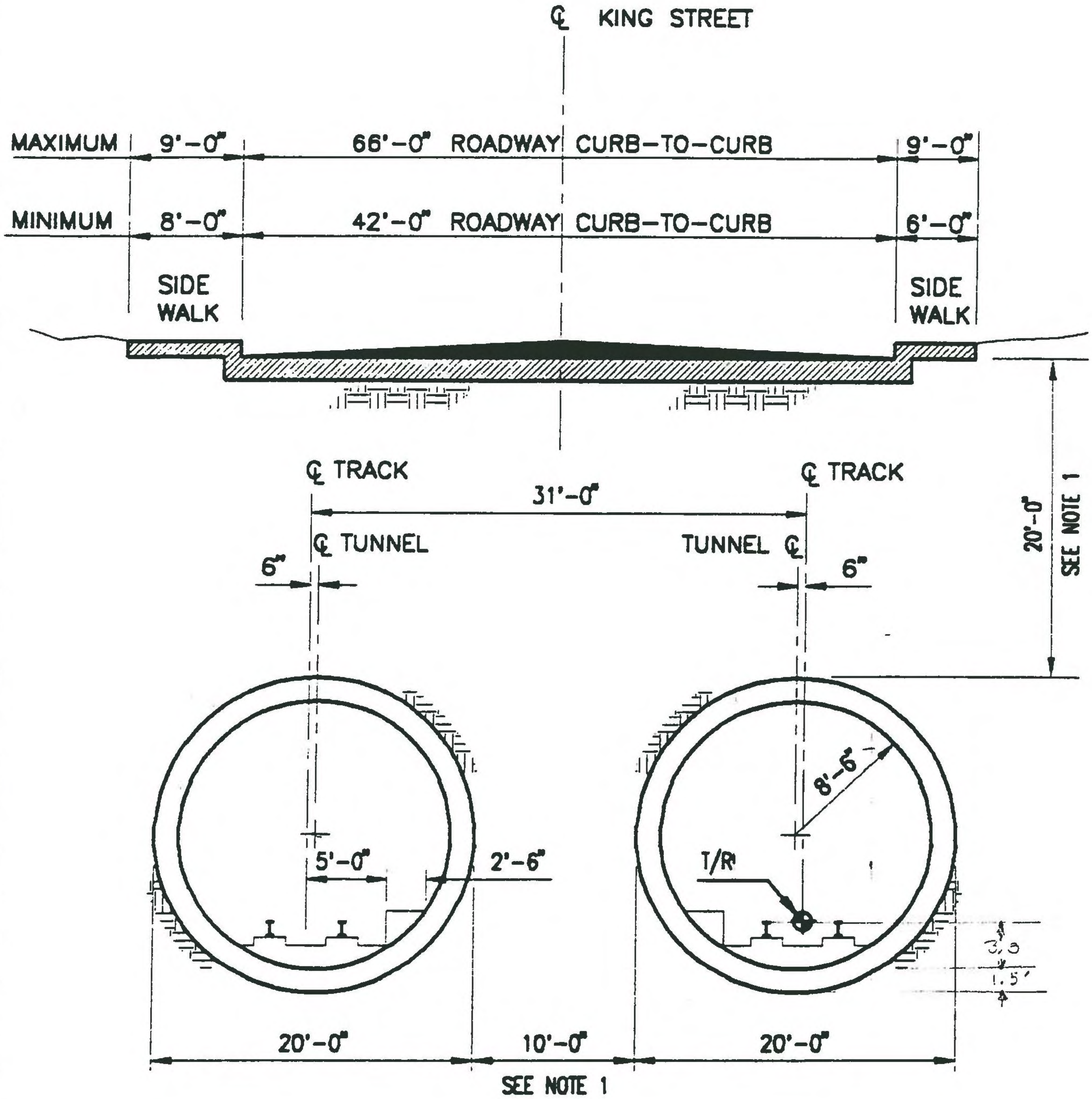


SKETCH 5.1 – CUT AND COVER TUNNEL

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS A MINIMUM VALUE, PROVIDING RESERVE SPACE FOR EXISTING AND FUTURE UTILITIES.

2. T/R = TOP OF RAIL

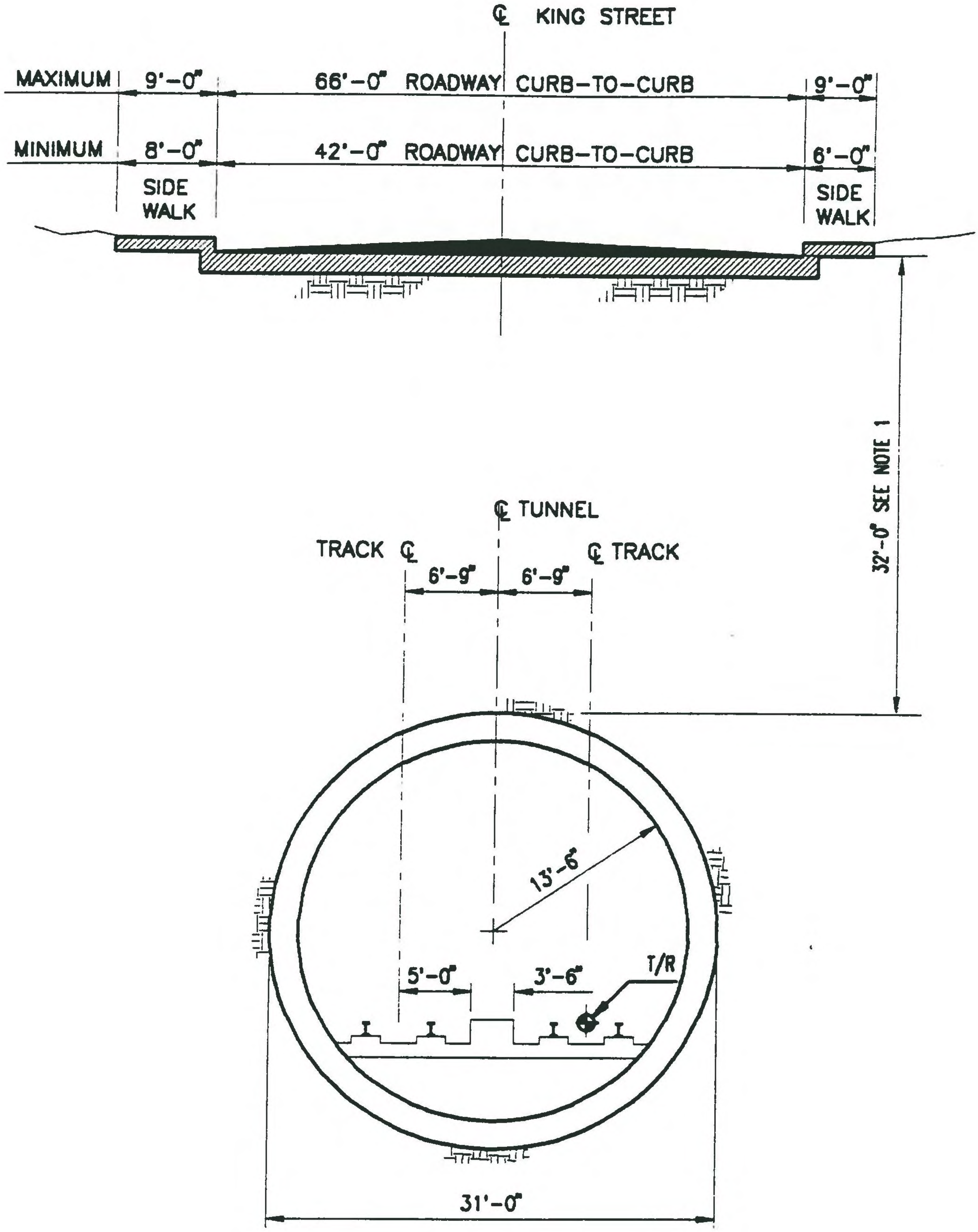


SKETCH 5.2 – TWIN CIRCULAR TUNNELS

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL

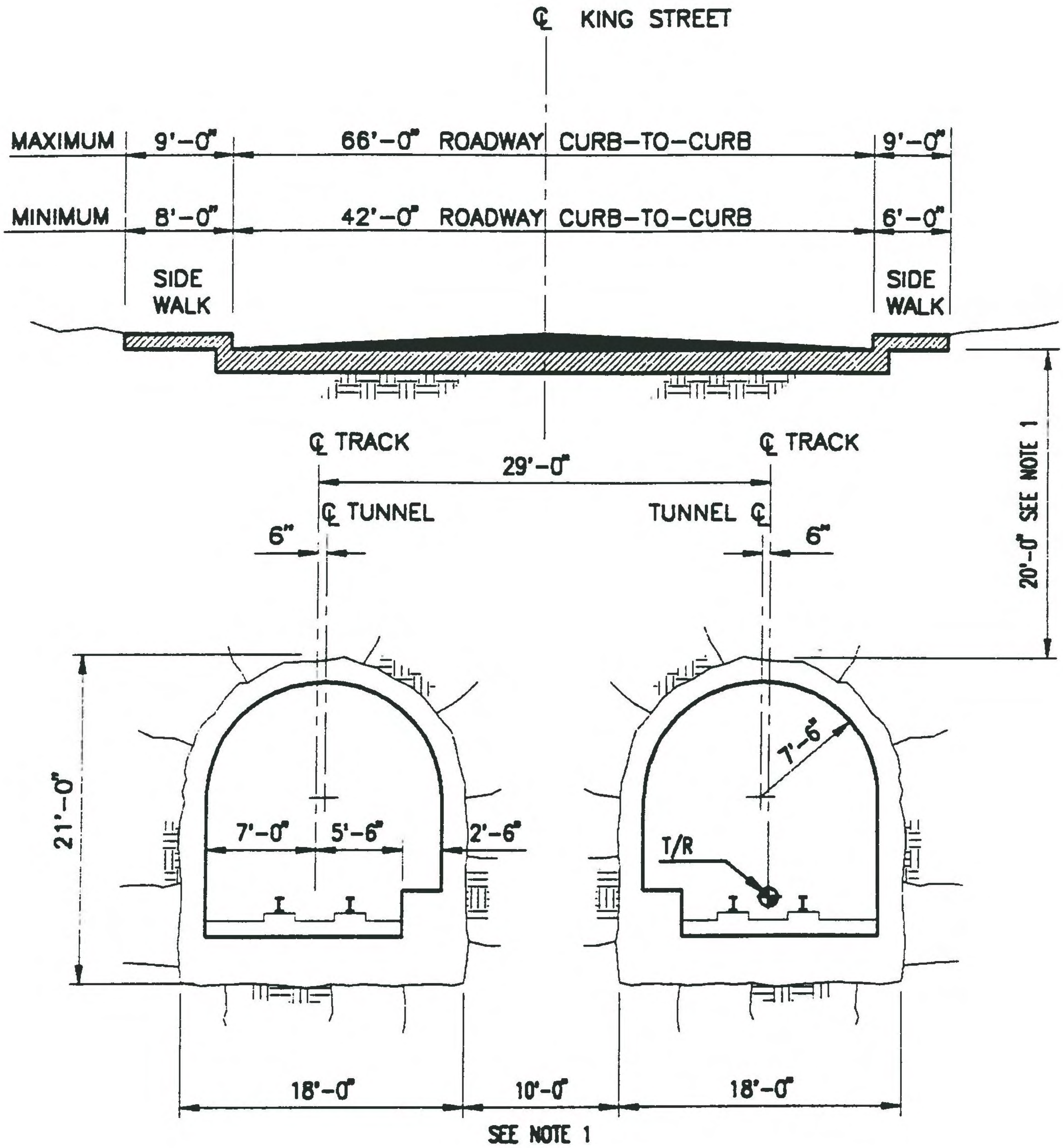


SKETCH 5.3 - SINGLE CIRCULAR TUNNEL (DUAL TRACK)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL

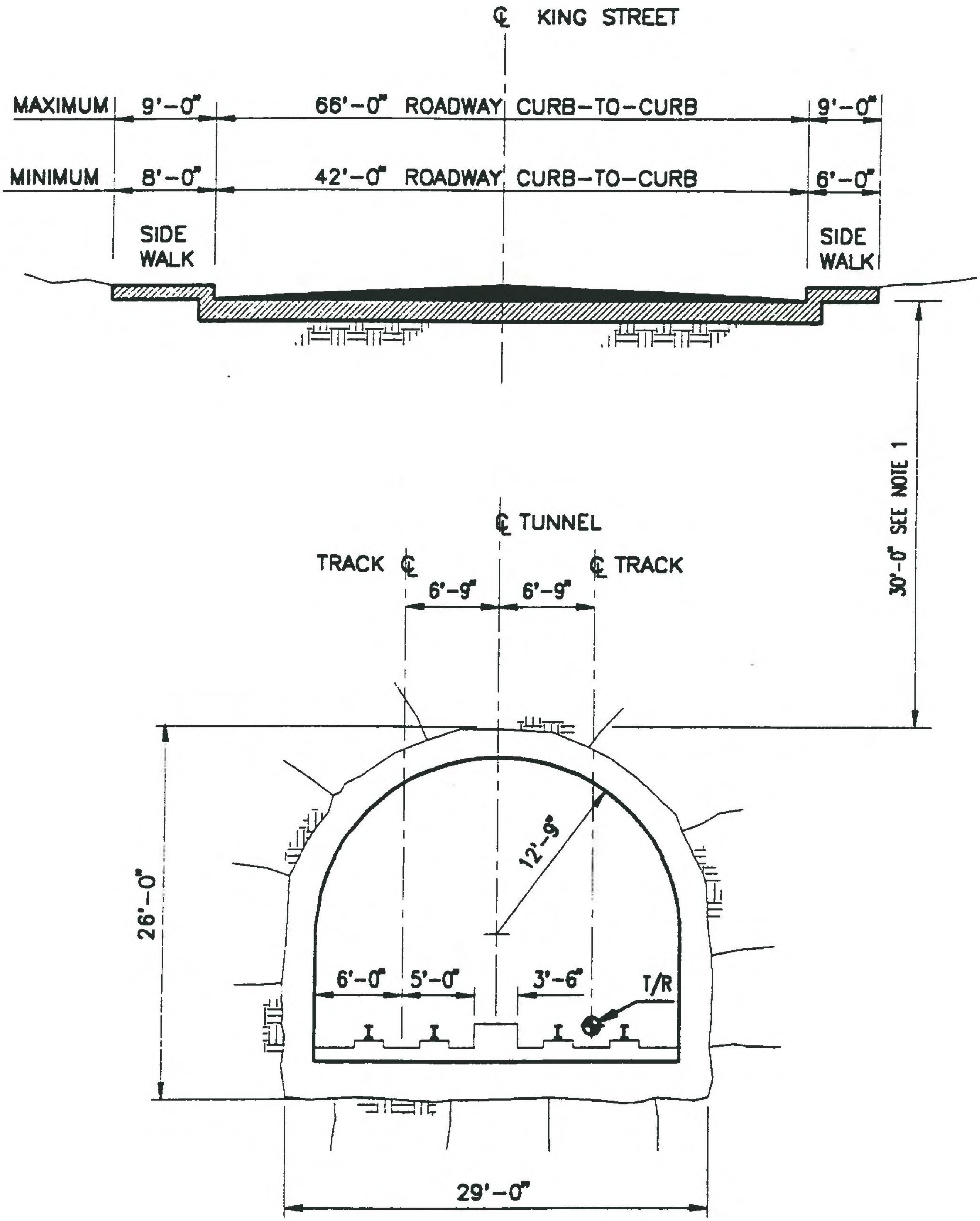


SKETCH 5.4 – TWIN HORSESHOE TUNNELS

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL



SKETCH 5.5 – SINGLE HORSESHOE TUNNEL (DUAL TRACK)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL

5.3 Station Structures

The proposed King Street Subway would incorporate two underground passenger stations within the project limits. Both stations are located along King Street; one near the intersection of King and Bethel streets, the other near the intersection of King and Punchbowl streets.

Underground subway stations are typically very large and technically complex structures. Construction generally occurs in the right-of-way of a busy downtown street, typically within an intersection. The construction contractor is forced to deal with a maze of buried utilities without disrupting service, maintain traffic flow around the construction site, and safeguard the surrounding buildings from damage. In addition, he must minimize the negative impacts of his activities to the neighboring businesses and residences.

In general, two methods of providing an underground space for construction of the station are available: a cut-and-cover excavation, or a mined-cavern excavation. Both methods have various advantages and disadvantages depending upon site specific conditions. This section will provide an overview of each method and discuss the applicability of each to the King Street Subway.

5.3.1 Cut-and-Cover Station Structures

Cut-and-cover excavation is the traditional method of underground construction for large structures such as subway stations. It is a relatively straight forward method familiar to many general contractors, utilizing readily available technology. The specific features of a cut-and-cover subway station are very similar to those described in Section 5.2.1 for the line structures. The primary differences entail the size of the structure and associated depth of excavation. In addition, station structures typically have specifications against groundwater infiltration that are more stringent than those specified for cut-and-cover running tunnels.

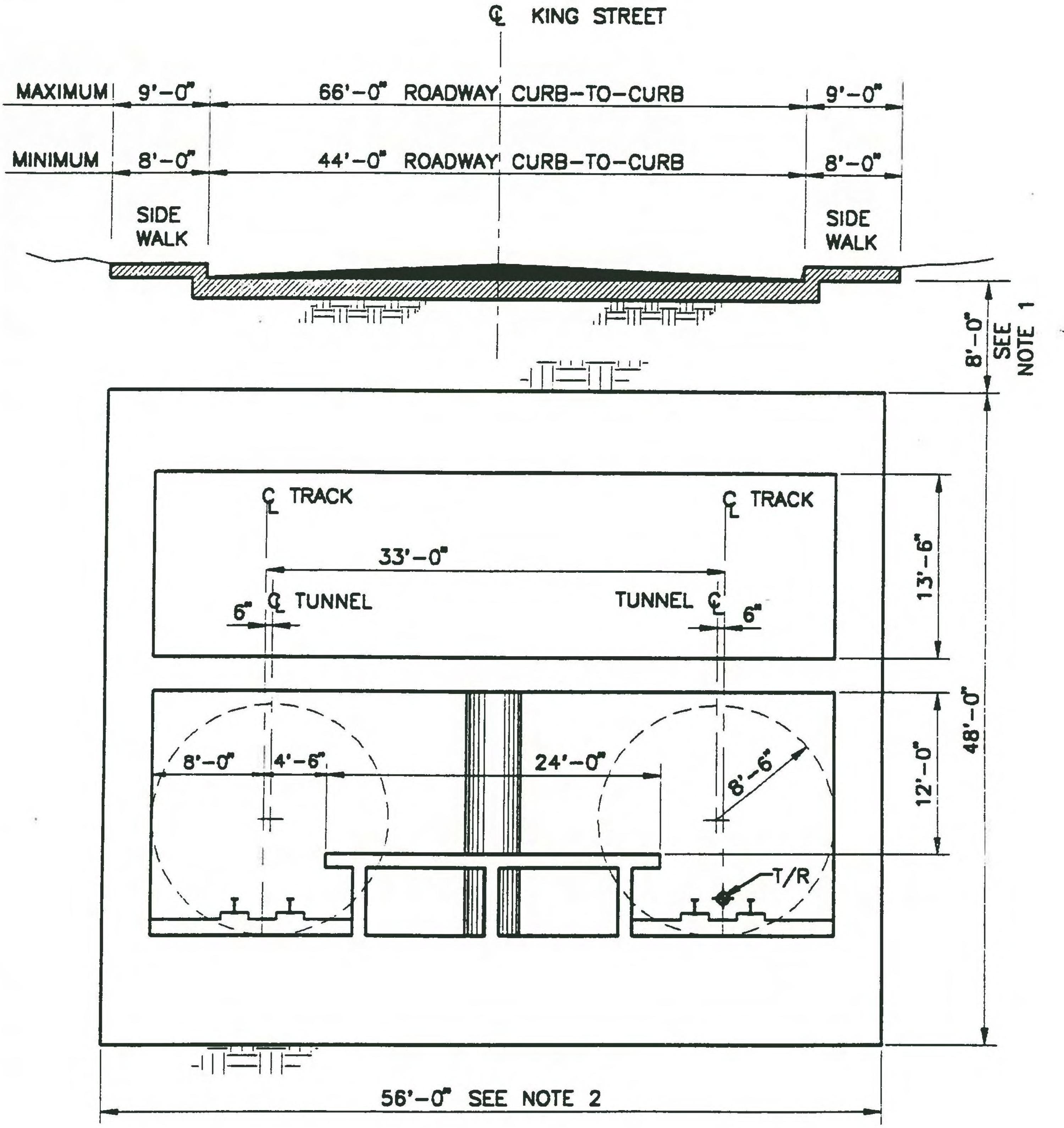
There is adequate width along the King Street right-of-way to accommodate a traditional subway station, configured as either a center or side platform station. When evaluated in terms of pedestrian circulation, the center platform station configuration is considered superior to the side platform alternative. Sketch 5.6 illustrates a prototypical center platform station with a mezzanine, that would be suitable for the King/Bethel and King/Punchbowl stations. With a below-grade mezzanine level, multiple access points to the center platform stations would be possible, including through adjacent buildings, and specifically through a connection between the Fort Street Mall pedestrian underpass and the King/Bethel Station.

5.3.2 Mined Cavern Station Structures

Many modern subway systems have passenger stations constructed with mined-cavern excavation techniques. The construction of these stations is often complex; however, the benefit associated with minimized surface disruptions generally exceed the negative aspects with mining underground station caverns. Section 5.2.2 provides a general introduction to mined tunnel concepts, which is also applicable to the design of station caverns. The principal difference between the two facilities includes size, depth of excavation, and significantly, the geometry of the respective cross sections.

Due to the irregular shape of underground passenger stations, the cavern excavation is usually performed by "hand-mining" techniques. These techniques include excavation by mechanical equipment such as road headers, hand-held equipment, or drill-and-blast methods. The site-specific geology is instrumental in determining the selected excavation method. Ultimately, large volumes of earth are removed from below grade, either through a tunnel portal or through a vertical access shaft. The structural stability of the resultant void or cavern is usually ensured by the installation of either temporary or permanent lining systems. There are a multitude of lining systems that effectively provide the required stability, each with particular characteristics suitable for specific environments.

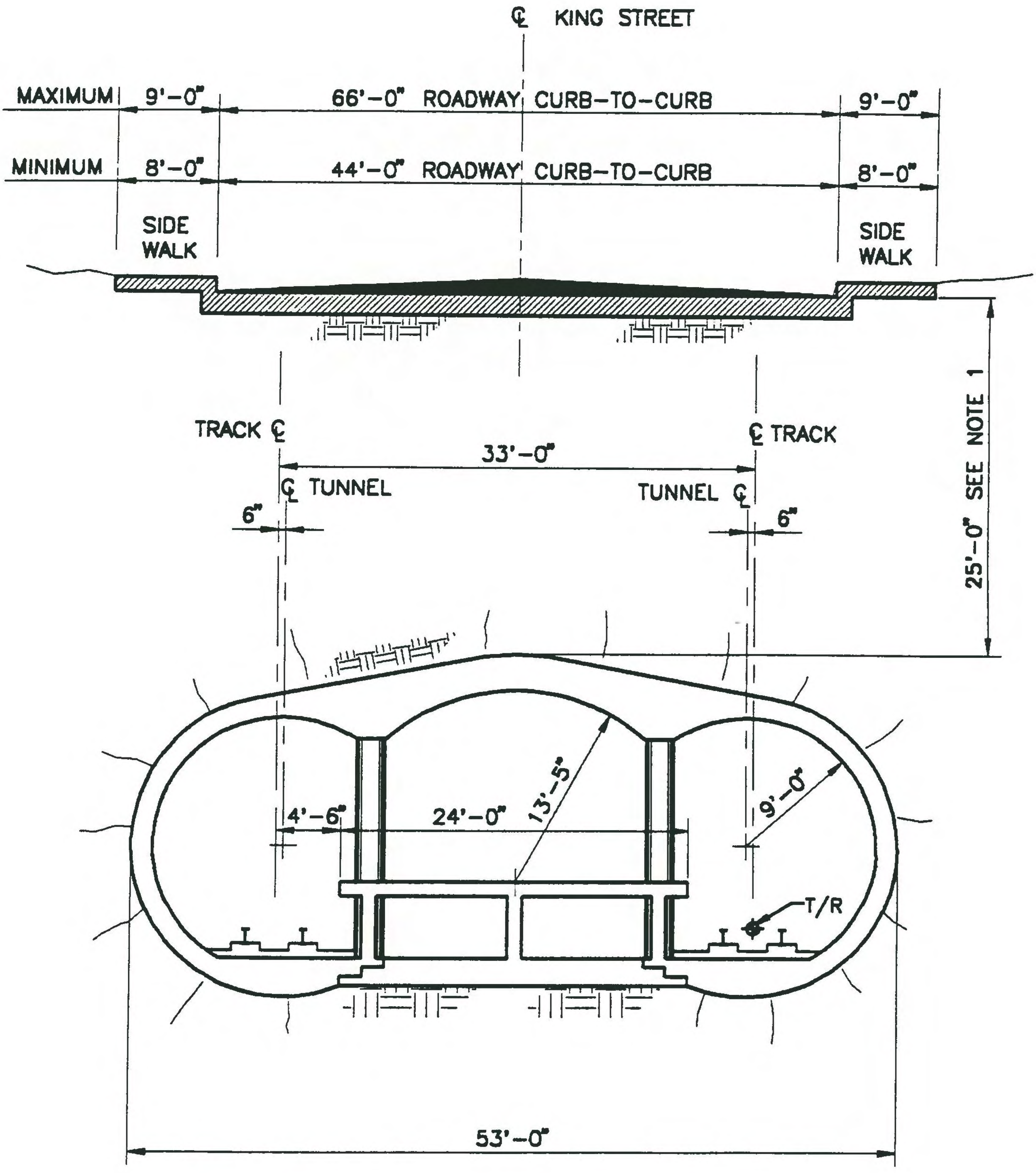
Ground deformation and surface settlement are influenced by parameters that include the volume of excavation and depth of cover above the station crown. In consideration of the less than ideal soil properties along the King Street alignment it appears that a relatively small station cross section would be advantageous if the mined-cavern solution were implemented. A mined center platform station without an independent mezzanine level is illustrated by Sketch 5.7. The station can be constructed within the limits of the King Street right-of-way, however, additional space would be required for ticketing/concourse areas and ancillary rooms. This space may be located at either end of the station platform or possibly beyond the street right-of-way as a joint development venture.



SKETCH 5.6 – CENTER PLATFORM STATION (CUT AND COVER)

NTS

NOTES:
1. DIMENSION VARIES. THE INDICATED, MINIMUM VALUE IS RESERVED FOR EXISTING AND FUTURE UTILITIES.
2. CONSTRUCTION WIDTH WILL EXCEED STRUCTURE WIDTH BY AN AMOUNT CONTINGENT UPON THE SELECTED CONSTRUCTION TECHNIQUE.
3. T/R = TOP OF RAIL.



SKETCH 5.7 - CENTER PLATFORM STATION (MINED)

NTS

NOTES: 1. DIMENSION VARIES. THE INDICATED DIMENSION IS THE PREFERRED MINIMUM VALUE FOR CLEAR COVER REQUIREMENTS.

2. T/R = TOP OF RAIL.

5.4 Portal Structures

The guideway alignment will transition below grade and reemerge within the King Street Subway project limits. Portal structures are designed to support the guideway transition from the ground surface to the below-grade tunnels.

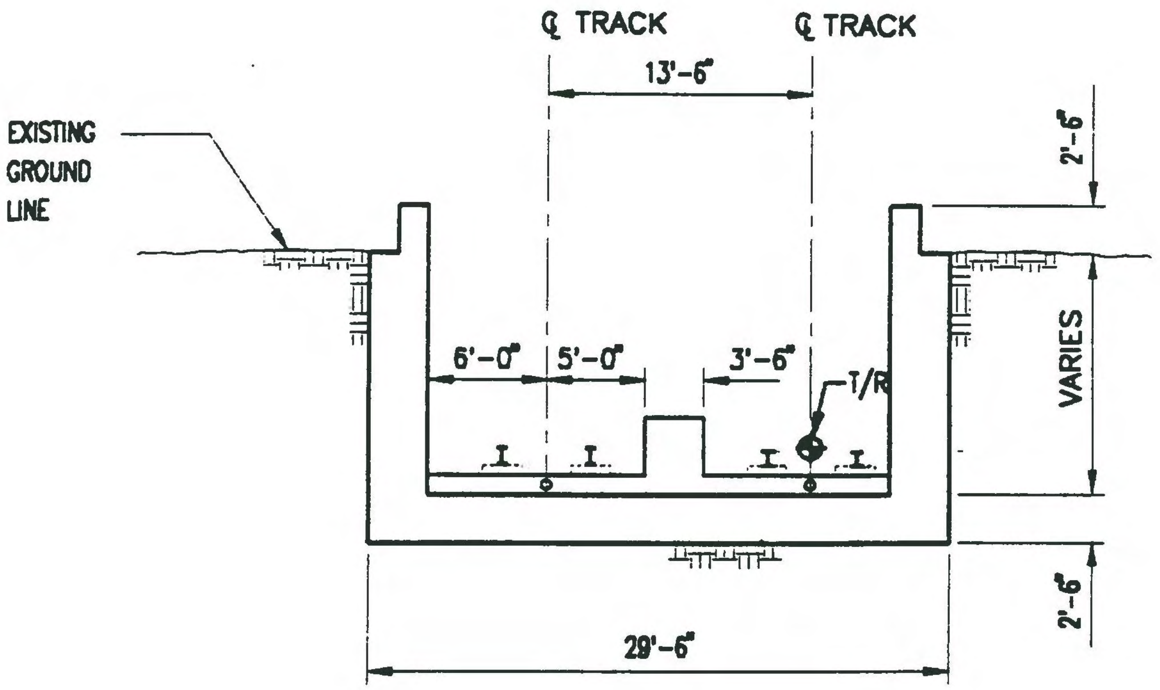
5.4.1 Configurations

Tunnel portals are generally composed of a length of open-cut or retaining-wall structure followed by the actual tunnel entrance. The length of retained cut is typically a function of the running surface profile grade line, and the surrounding ground contours. The portal entrance is frequently followed by a transition structure that supports the shallow or relatively unstable ground near the tunnel entrance. The transition structure commonly consists of a cut-and-cover box structure that terminates at a location where the depth of overburden is suitable to support the designed tunnel section. Sketch 5.8 illustrates a typical portal structure.

Design solutions for the tunnel entrance and associated portal geometry must consider the dynamics of a train passing in and out of the tunnel. Tunnel portals are designed to minimize the rate-of-change of air pressure of a train passing through the portal. Attenuation or sudden changes in air pressure and noise levels should be avoided. Pressure rise is a function of the cross-sectional area of the portal entrance and the velocity of the passing train. Design solutions may entail flared portals or a series of perforations along the interior wall of a double-cell box.

Portal structures are configured to match the tunnel geometry and retain the surrounding embankments. The associated retaining structures typically consist of either U-wall sections, where both vertical walls are continuous with a full-width base slab, or alternately a section composed of individual retaining walls.

In designing the location of portal structures and the termination of U-wall sections, the potential of flooding resulting from high water levels near bodies of water and tributary watercourses, or from local storm runoff must be considered. Provisions should also be made for immediate and effective removal of water from rainfall, drainage, groundwater seepage, or any other source. Where applicable, the structure design must resist hydrostatic uplift.



SKETCH 5.8 - PORTAL STRUCTURE U-WALL

NTS

NOTES: 1. T/R = TOP OF RAIL

5.5 Conclusion

The structural configurations presented in this report are all suitable for the King street alignment when evaluated relative to the geometric and physical constraints that exist within the subway project limits. However, the selection of a tunneling system for the King Street Subway is intimately related to the adopted construction method. The following section examines conceivable construction methods in conjunction with the currently available design information, and concludes with a recommended conceptual level design solution.

6.0 CONSTRUCTION METHODS

6.1 Introduction

Subway construction generally occurs in urban areas within the right-of-way of high-density downtown streets that usually exhibit large volumes of vehicular and pedestrian traffic. Construction contractors must deal with a maze of buried utilities without disrupting service, maintain traffic flow around the construction site, and safeguard the surrounding buildings from damage. In addition, the selected construction method must minimize negative impacts to neighboring businesses and residences.

In general, two methods of constructing facilities for the subway passenger stations and running tunnels are usually contemplated. The principal methods entail either cut-and-cover construction, or mined tunnel excavation, each possesses particular advantages and disadvantageous that are dependent upon the site specific conditions. This Section will provide an overview of each method and discuss their applicability to the King Street environment.

6.2 Cut-and-Cover Excavations

Cut-and-cover excavation is the traditional method of underground construction for large structures such as subway stations. In cut-and-cover excavation, a temporary earth retaining system is first installed from the ground surface. The retaining system might consist of steel sheet piles, soldier piles, and lagging or a concrete slurry wall. The choice of system would be dependent upon the depth of excavation, geotechnical conditions, and proximity of surrounding structures.

The earth between the retaining walls is progressively removed and struts placed between the walls to support the excavation. Once the desired elevation is reached, the structure is constructed within the excavation, the excavation backfilled and the temporary retaining system removed or abandoned in place.

Construction is complicated by the presence of a high water table and permeable soils. Such a condition requires the installation and operation of dewatering equipment to allow the construction to progress safely. If the soil consists of soft clays or silts, the lateral loads on the retaining walls will be sizeable, especially for a deep excavation as required for subway construction. The presence of adjacent structures must be carefully considered before beginning construction, and the temporary retaining system should be designed and constructed to minimize damage to these structures.

It is anticipated that any cut-and-cover excavation along the King Street alignment would be accomplished using concrete slurry walls as the earth retaining structure. A slurry wall has benefits in that it can be used to limit deflections of adjacent buildings much more effectively than other systems. The second advantage of the slurry wall is that it can be used to isolate the excavation (a cut-off wall) so that dewatering efforts within the excavation will not draw down the surrounding water table, thereby causing additional settlement of adjacent buildings. Finally, if the slurry walls are appropriately designed and constructed, they can be utilized as the final structural walls for the stations or running tunnels, resulting in potential savings in both construction time and cost.

Regardless of the required structural configuration, the construction of any cut-and-cover tunnel follows the general procedures outlined above; i.e., installation of the earth retaining system, excavation and bracing, construction of the structure, and finally backfilling of the excavation.

There are two major variations of traditional cut-and-cover construction that are frequently referred to as "bottom-up" and "top-down" construction. Both methods are applicable to the construction of underground subways and are addressed separately below.

6.2.1 Bottom-Up Construction

Bottom-up construction is the traditional and most commonly utilized method of cut-and-cover construction. This method requires the installation of struts between the temporary retaining walls in a progressive manner as the excavation proceeds downward. The result is that as the excavation progresses, the contractor has a large open hole within which to work. This large open hole makes it easy for the contractor to complete the excavation, provides excellent construction access and gives him plenty of room to construct the station within the excavation.

The King Street Subway alignment runs through permeable soils, completely below the water table; therefore, it will be necessary to dewater the site ahead of the excavation. Once the lowest excavation elevation is reached, the station base slab is constructed to stabilize the bottom of the retaining walls. In progressive order working back upward, intermediate slabs and finally the roof slab are constructed, allowing removal of all remaining struts. Following the installation of waterproofing materials, the excavation is backfilled and the street surface restored. All further work can take place within the confines of the station shell and be supplied at limited access points.

A tremendous volume of spoil materials will have to be removed from the site during excavation. An equally large amount of concrete, reinforcing steel, and other construction materials will have to enter the site during construction of the subway facilities. The large open hole provided by the bottom-up construction method provides almost unlimited access to the site and easily facilitates these activities. Construction vehicle access can be provided by the installation of a temporary deck over a portion of the excavation to allow partial restoration of vehicular traffic on the street above.

6.2.2 Top-Down Construction

Top-down construction is a specialized form of cut-and-cover excavation that is increasingly being used for the construction of large underground structures such as subway stations. A small modification of the traditional excavation procedure makes the top-down method a much preferred alternative for construction in crowded urban areas. The primary benefit is to minimize surface disruption.

In top-down construction, the temporary earth retaining walls are installed in the normal fashion. These walls are almost always concrete constructed by the slurry-wall method and are normally intended to act as the permanent structure walls. In suitable geologic environments, the concrete slurry walls can also act as cut-off walls to prevent drawdown of the water table outside of the construction site and related surface settlements during dewatering operations.

Excavation proceeds to the elevation corresponding to the underside of the box structure roof slab. At this point in the sequence, the roof slab is constructed and connected to the slurry walls. Large access holes are left in the roof slab to allow further excavation to continue.

Once the roof slab is completed and the waterproofing applied, the excavation can be backfilled up to the street level with provisions made for continuing access through the holes left in the roof slab and the street resurfaced and opened to traffic. Excavation for the subway structure proceeds by mining with front-end loaders under the roof slab and disposal of the spoils through the access holes. The process is repeated at each intermediate slab level until finally the base slab level is reached and excavation is completed.

From the owners point of view, the advantages of the top-down construction are readily apparent. The first, of course, is that traffic can be restored quickly. This should be a major consideration for the King Street Subway. The second, is that by covering the excavation early, the construction noise, dust and associated disruption are reduced considerably. Thirdly, the contractor is forced to carry out all spoil removal and material supply efforts at one or two points, the access holes. These can be located to minimize impact to the surrounding businesses and residents.

The greatest advantage of the top-down method may be attributed to the protection from ground movements that it offers to existing buildings surrounding the construction site. By constructing the three-to-six-foot-thick concrete roof slab before continuing excavation, the contractor has in fact installed a rigid, nearly incompressible strut between the walls. Similarly, by installing each subsequent slab before proceeding with the excavation, the inward wall deflections and related surface settlements are reduced to the absolute minimum obtainable.

6.2.3 Concerns

Disadvantages of cut-and-cover construction include maintaining safety around the excavation, conflicts with buried utilities, difficulty in limiting the settlement of surrounding structures, and long-term disruption of surface activities. With the exception of conflicts with buried utilities, all of these concerns are greatly reduced, if not eliminated, with the adoption of top-down construction.

A major concern in any large excavation planned for a public street is conflict with underground utilities. This problem will exist with the adoption of either bottom-up or top-down construction. While cut-and-cover tunnels are normally located a considerable distance below the street level for operational requirements, the roof of an underground station is generally quite close to the ground surface.

It is normally possible to temporarily support the underground utilities as the tunnel excavation proceeds. However, it may be necessary to physically relocate particularly deep utilities. The utilities under King Street, as currently known, have been reviewed and no serious conflicts with the stations have been identified.

From an engineering standpoint, the greatest problem that occurs with cut-and-cover construction has to do with the surrounding surface settlements generated by the excavation. The extent of the problem can be reduced by using thick slurry walls, close strut spacing and high levels of strut preload. However, the inward wall deflection and subsequent surface settlements will often still be unacceptable. This is particularly true where old masonry buildings are found adjacent to deep excavations.

Settlement of surrounding structures can be minimized by proper design and careful construction of the earth retaining system and bracing combined with a diligent ground movement monitoring program and building protection plan. However, even with the most careful planning and construction, some settlement of existing structures can be expected. The goal should be to try to limit such settlement to an absolute minimum.

Long-term disruption of surface activities covers several aspects of life in the area surrounding a cut-and-cover construction site. Initially, traffic at the construction site will need to be detoured while the initial excavation is accomplished. This detour would cause significant disruption along King Street, particularly at the proposed passenger station locations. To reduce the impact, public transit could be rerouted to other parallel city streets.

A further disruption to the local quality of life is caused by the construction activities themselves. This disruption includes noise and dust generated by the construction haul vehicles and heavy equipment working at the site, problems with restricted access to businesses, and temporary utility outages. These potential problems are usually addressed in the technical specifications that accompany construction contract documents. For example, construction traffic movements might be limited to daylight working hours to avoid disturbing local residents at night. Similarly, disturbance of local businesses can be held to a minimum by careful planning and rigid technical specifications.

6.3 Mined-Tunnel Excavations

The local subsurface geology is instrumental in determining the proposed tunnel design solution and the corresponding method of tunnel construction. The design considerations are radically different between line tunnels and stations caverns due to their differences in size and geometric form. The following sections discuss the appropriate methods of tunneling line tunnels and station caverns in the King Street underground environment.

6.3.1 Mined Running Tunnels

6.3.1.1 *Tunneling Methods*

Slurry Shield

The Slurry Shield is a tunnel boring machine (TBM) designed to work in soft-ground below the water table. It is a closed-face, fully enclosed TBM. As the Slurry Shield is forced ahead into the ground by jacks, the rotating cutter head, fitted with cutting tools, cuts, grinds, and excavates the ground materials. As the Slurry Shield advances, a slurry of bentonite is automatically mixed with the ground just ahead of the cutter head. This bentonite slurry enters the ground materials under an appropriately designed pressure and forms an impervious "cake" which resists the groundwater pressure.

The slurry shield TBM is highly mechanized and typically computerized. Because the men never see the ground, they must rely on instruments to determine the amount of materials being excavated; too much material excavated per foot of advance would result in excessive settlement at the ground surface. Bentonite slurry is expensive, therefore, it is separated and recycled for continued use. Bentonite reclamation facilities are located on the ground surface at regular intervals along the route for this purpose.

Earth Pressure Balance (EPB) Shield

The Earth Pressure Balance (EPB) Shield is a variation of the slurry shield. The men work inside the protection of the EPB shield, operating the TBM and erecting the support system. The rotating EPB cutter head, fitted with appropriate cutters, is jacked into the ground and excavates it. However, instead of using a slurry made of bentonite to resist the groundwater, a slurry made of the earth and water actually encountered at the face is mixed inside a pressurized chamber. This mixture of the earth and water is carefully monitored by various instruments, and is kept at the necessary pressure and density inside the pressurized chamber to resist the outside soil and groundwater pressure. The material is discharged without loss of pressure by a screw conveyor, which is synchronized to the advance of the shield. No cleaning and/or recycling of the earth mixture is needed.

The excavated volume and the discharge volume must be the same. To achieve this, the advance of the EPB shield is controlled either by monitoring the discharged muck volume, and/or by monitoring the earth pressure of the face. Earth pressure within the pressure chamber is controlled by observing the thrust of the shield jacks, torque and revolving speed of the cutter frame and the torque and revolving speed of the screw conveyor.

The EPB shield, or the slurry shield, can be mounted with disc cutters, for hard-rock excavation as well as being mounted with conventional soft ground ripper and rake teeth. These hard-rock cutters can be inserted from inside the TBM. Using high jacking pressures, modern EPB TBMs can cut through very hard rock such as the basalts that might occasionally be found in the King Street Subway as well as soft ground below the water table.

Modern TBMs can be designed to cut through unseen obstacles such as wood or concrete piles. Tie-backs, which may be encountered, or large boulders may be handled by a special operation that entails pressurizing a small area in front of the TBM, allowing a miner to exit and work in the face ahead of the TBM to remove obstacles by hand.

Extruded Liner EPB Shield

An Extruded Liner EPB Shield machine is a variation of the standard EPB shield, which extrudes a freshly-poured concrete lining as it advances. The concrete lining is reinforced with steel fibers that are mixed directly into the concrete. This innovative EPB machine may not be suitable in the Honolulu corals due to the possibility of losing significant volumes of concrete into the voided corals.

Compressed Air Tunneling

Compressed-air tunnel construction is an old technique that relies on a pressurized environment to resist groundwater inflow.

The compressed air pressure is designed to equalize the groundwater pressure and thus prevent water from infiltrating the tunnel excavation. The compressed air also serves to drive groundwater out of the soil adjacent to the excavation, thus, stabilizing and improving the properties of most soils to a significant degree. However, if the required air pressure exceeds about 12 psi gage, negative health effects begin to occur, and the length of work shifts are restricted.

Generally, in compressed-air tunneling, men work inside an open shield and excavate the tunnel by hand mining. Usually, they erect a continuous support system inside the shield and advance the tunnel using jacks. The face of the shield is open, and the ground can be viewed during construction, which can be advantageous when obstacles such as boulders or tiebacks are encountered.

Tunnels below the water table have been built using compressed air without a shield. For example, the New Austrian Tunneling Method stabilizes soil with shotcrete shortly after excavation.

Compressed-air tunneling involves a risk of physical injury, surface settlement, tunnel collapse, or existing building damage when groundwater, soil, or both enter the excavation in the event of a system failure. The risk in compressed-air tunneling is that the men are exposed directly to the ground, and if there is a failure of the system, the men can be harmed by the entry of groundwater, or soil, or both.

A rapid inflow of soil and water can also occur if the air pressure inadvertently exceeds that necessary to balance the inward groundwater pressure. In such a case, a "blowout" can occur, where the compressed air escapes through a path away from the tunnel. Voids in coral or basalt, gravel beds, abandoned wells or shafts, wooden piles, or soft muds on a stream bottom, could promote blowouts. Because the compressed-air systems are unable to perform properly when large amounts of air are escaping, blowouts are rapidly followed by inflows of soil and water.

Along the King Street alignment, the compressed-air tunneling method appears to have limited applications. It may be suitable for shorter tunnels within the specific problem areas, or for unique arrangements such as personnel cross passages located between running tunnels.

New Austrian Tunneling Method (NATM)

The New Austrian Tunneling Method (NATM) pioneered in the 1930s basically involves a ground excavation method that is promptly stabilized with shotcrete and typically relies on the ground strength for permanent tunnel support. In theory, the thin shotcrete layer prevents small fallouts and unravelling, and the mass of in situ rock or ground subsequently supports itself by arch action within the ground mass.

NATM was first used in rock tunnels, that were initially excavated with the drill and blast method, and typically reinforced with rock bolts that were installed along with the supporting shotcrete. However, in recent years NATM has been applied successfully to soft-ground conditions. The excavation is made carefully with shotcrete applied promptly, and generally tunnel progress is relatively slow. However, by quickly supporting the excavation, settlement is kept to a minimum and tunneling close to sensitive structures has been successfully completed using NATM.

The natural water table elevation is a serious disadvantage when considering NATM for the King Street Subway tunnel. To adhere, shotcrete must be applied to a nearly-dry ground surface. The NATM can be used with compressed air, but the previously noted, undesirable characteristics of compressed air would be present.

Dewatering with deep wells along the tunnel route may be a viable method to control groundwater in conjunction with NATM. However, the cost of installing the deep wells and the resulting lowering of the groundwater level with possible ground settlement problems makes this method unattractive.

6.3.1.2 *Concerns*

Groundwater

The King Street Subway alignment is located well below sea level and the coincident water table. Various soft-ground materials, including lagoonal deposits, alluvial sands, silts, clays, and corals, with various degrees of cementation are all found within the alignment. In addition, isolated outcrops of basalt may be encountered. Tunneling in the soft grounds is made complex by the presence of groundwater.

During tunnel construction and service operation, it is imperative that the groundwater inflow be controlled. Even slow inflow of groundwater can cause piping and migration of fines into the tunnel, inducing very large surface settlements. Rapid water inflow into tunnels could be catastrophic. The design of the tunnel lining must insure permanent watertightness; some projects have failed when fine soils migrated into the tunnel in large quantities through the lining joints because of groundwater action. The resulting irregular voids may expose the tunnel lining to unbalanced loads that greatly exceed the ordinary design parameters.

Surface Settlement

Tunneling in soft ground invariably results in some "ground loss" or over-excavation beyond the theoretical volume that causes a collapse and rearrangement of the ground particles. This in turn produces a settlement trough above the excavation. In metropolitan areas, this surface settlement can cause disruption of streets, utilities, and building structures. Adjacent buildings or structures may require protection to avoid damage due to this settlement.

As tunnels are advanced in soft ground, ground loss occurs due to several practical problems. TBMs are advanced in a series of discreet "shoves" of 3 to 6 feet at a time, and if the TBM is misaligned, there will be over excavation. The support system must be assembled, moved out of the shield, erected, and grouted into place. The TBM shield, of course, initially excavates a tunnel of larger diameter than the support system, and there may be ground loss before the voids behind the support system can be grouted. If an open-faced TBM is employed, and the ground is not firm, some ravelling and fallout may occur at the face. All of the separate sources of "lost ground" are heavily influenced by the construction procedure, experience, and skill of the workmen, but some loss is inevitable. Successful tunneling results in excess lost ground amounting to about 2 percent of the excavated volume. Poor tunneling technique can result in 5 percent lost ground.

This ground loss at the tunnel causes a rearrangement of the ground above the tunnel. Measurements made at many soft-ground tunnels indicate that the surface of the ground will settle an amount whose volume is approximately equal to the volume of the "lost ground" over excavated and/or lost at tunnel depth.

An empirical approach exists, based on field evidence that is commonly used to estimate the configuration of the settlement trough at the ground surface above the excavation of the tunnel. However, the predicted rearrangement of the ground becomes quite complex when a second tunnel is excavated in the vicinity of a previously bored tunnel.

Dewatering may cause a consolidation of soft, fine-grained sediments, which is an additional source of settlement. Most of the soft ground along the subway alignment is granular (coralline sands, gravels, and cemented coral) and, thus, not subject to consolidation. Fine-grained alluvial silt and clay sediments do exist at relatively deep elevations and their consolidation could introduce additional displacements. In isolated locations fine sediments, susceptible to consolidation, are found near the ground surface.

A settlement trough generated by tunneling through open country will generally go unnoticed with no objection or adverse consequence. In urban areas, the settlement trough may extend below buildings, and the resulting displacements can cause architectural or structural damage to existing buildings. Prudent owners of tunnels perform preconstruction surveys, make detailed photographs of the adjacent buildings, and implement sophisticated monitoring programs during construction to provide historical documentation of actual or perceived changes. In many legitimate cases settlement damage during tunneling must be acknowledged and remedied.

There are numerous well-cemented coral beds along the route of the proposed King Street Subway. Experience with similar conditions indicates that these beds will suffer negligible settlement. However, these coral beds are not continuous, and so at irregular intervals uncemented materials will be found that will undergo some settlement. The actual settlement is highly unpredictable. Logically, a monitoring system designed to measure actual settlement and possible building distress would be installed.

Geotechnical instrumentation to monitor ground movement and especially ground settlement, is an essential part of ground control in tunneling and subway station excavation. Geotechnical measuring instruments can be read so promptly that the tunnel or cut-and-cover excavation techniques can be modified or even halted if necessary, within a matter of minutes. Remedial measures for excessive settlement or other hazardous ground movement must be tailor-made for the particular problem, but cement or chemical grouting, "compaction" grouting, and other techniques are well known and can be used.

6.3.2 Mined Station Caverns

6.3.2.1 *Tunneling Methods*

Many modern subway systems have passenger stations constructed with mined-cavern excavation techniques. The construction of these stations is often complex; however, the benefit associated with minimized surface disruptions generally exceed the negative aspects associated with mining underground station caverns.

The geological conditions along the King Street Subway alignment are not favorable for the construction of mined cavern subway stations. The geology is composed of soft ground and pervious corals with voids, well below the water table. The groundwater would have to be controlled with compressed air or by dewatering with deep wells. The following discussions will be limited to those lining systems and associated construction methods that may potentially be feasible for the King Street Subway environment.

New Austrian Tunneling Method (NATM)

One technique that is used in modern cavern construction is the New Austrian Tunneling Method (NATM), which often uses drill-and-blast methods to excavate the opening and shotcrete to promptly support the newly excavated opening. NATM advance rates are slow because the shotcrete is applied after each short advance effort, but the prompt support by the shotcrete often reduces the surface settlement above the cavern.

The presence of a high water table will greatly complicate the situation. In soft ground, the excavation would have to be supported immediately, and for a large mined cavern, shotcrete is the preferred support material. Shotcrete will not adhere to wet, soft ground, and normally compressed air is used to "dry out" the ground or deep wells to remove the groundwater would be necessary. However, the compressed air option is not desirable because of the pervious nature of the coral. Voids in the coral, filled with water but connected to the surface, could provide routes for the compressed air to escape. Any rapid loss of air pressure underground could be catastrophic.

The remaining option, which is to dewater the area using deep wells, is safer than the use of compressed air in the corals that exist along King Street. However, dewatering would require a significant drawdown of the water table with a correspondingly large radius of drawdown around the subway station. This widespread lowering of the water table by conventional dewatering is considered a threat to surrounding structures because of the possibility of increased surface settlements and building damage.

Jacked Pipe Arch

An alternate solution to soft-ground mined-cavern construction is to jack or drive a "pipe arch" of medium-sized steel or concrete pipes (perhaps 3 to 5 feet in diameter) along the roof. After this pipe arch is safely in place, excavation is made carefully under the protection of the pipe arch which is kept supported at all times.

Again, the construction effort is tedious and complicated by high ground water elevations. Additionally, the existence of corals at the proposed station locations would seriously curtail the ability to jack the pipe sections which form the initial arched roof.

6.3.2.2 *Concerns*

Construction of mined caverns below the water table is possible in favorable geological conditions, where the ground is sufficiently competent to resist the presence of groundwater. In some hard rocks free of joints, fissures, faults, and weathered zones, the water presents little difficulty and construction can proceed safely and economically. Pumps must be provided to remove the excess water.

If the geological material is jointed, faulted, and weathered, the presence of the water is a potential threat. If the water loosens the rock blocks or causes the weathered materials to erode, the entire rock mass may unravel and a rapid, unpredictable failure may occur.

If the geological material is soft ground, the presence of the water is an active threat. The water can loosen the soft ground materials and carry them away, with a consequent unravelling of the ground and imminent failure. Excavation in soft ground below the water table must be supported immediately. For large mined caverns of irregular shape, support is usually provided by shotcrete. For shotcrete to adhere properly, the ground must be stable and reasonably dry.

One solution to the problem of shotcrete placement on soft ground below the water table is the use of compressed air. The compressed air drives the groundwater away from the exposed face and, thus, "dries out" the soft ground long enough for the successful placement of the shotcrete. Compressed air does introduce difficulties such as health hazards, potential blow-outs resulting in rapid decompression, and construction complexities with associated cost implications.

A second solution to the problem of shotcrete placement on soft ground below the water table is to lower the water table until the work is "in the dry." This solution would mean conventional dewatering with deep wells for some hundreds of feet along the length of the proposed subway station. The resulting surface settlement due to this dewatering would extend for several thousands of feet in all directions from the dewatering, and requires careful evaluation before use.

6.4 Portal Construction

Tunnel portals are typically constructed using methods similar to those used for cut-and-cover construction as described in Section 6.2. The general procedures include installation of an earth-retaining system, excavation and bracing, followed by construction of the permanent structure. The only unique operation would possibly entail the stabilization of the ground around the actual tunnel portal.

The associated U-wall sections may be built using either an open- or retained-cut construction method. Open-cut construction would require a relatively wide right-of-way or construction easement because the excavation width is a function of slope stability and the depth of construction which gradually increases near the portal. There are right-of-way restrictions and physical constraints near the King Street Subway portals that limit the feasibility of pursuing open-cut construction. U-walls installed using retained-cut methods could be constructed adjacent to temporary sheet piles or as a diaphragm wall designed for temporary and permanent conditions.

The estimated groundwater elevation suggests that some dewatering will be required under any construction scenario. The implications of dewatering and associated merits of each construction scheme are similar to those cited for cut-and-cover construction.

6.5 Conclusion

The method used to construct the King Street Subway essentially pivots on the decision to utilize either the cut-and-cover or the bored tunnel techniques. For King Street, either system could be used. Each has respective advantages and disadvantages, but both techniques will provide a permanent facility that will perform with equivalent levels of satisfaction.

To minimize disruption to surface activities during the construction of the transit system line tunnels, particularly along the heavily traveled King Street alignment, cut-and-cover construction should be avoided. For this reason, where applicable, the order-of-magnitude cost estimate in Section 11 is based on a suitable bored tunnel construction method, which is generally less disruptive than cut-and-cover construction methods.

Section 5 describes several appropriate methods of tunneling in the King Street underground environment. They include Slurry Shield, Earth Pressure Balance (EPB) Shield, Extruded Liner EPB Shield, Compressed Air Tunneling, and the New Austrian Tunneling Method (NATM). Evaluated as a group, these construction methods can yield a variety of tunnel configurations with individual characteristics that must be analyzed relative to the King Street underground environment. The tunnel configurations examined for the King Street Subway included Twin Circular Tunnels, Single Circular Tunnel (Dual Track), Twin Horseshoe Tunnels, and a Single Horseshoe Tunnel (Dual Track). All of the identified schemes are feasible for King Street; however, based on the available data, the twin circular tunnel configuration was selected as being most appropriate, and used for deriving the order of magnitude cost estimate.

The overriding criteria that governed conceptual selection of the tunneling technique involved ground subsidence and ground water control. The operating characteristics of the Earth

Pressure Balance (EPB) Shield appears to be most suitable in responding to these critical criteria. The EPB Shield uses excavated ground within a sealed chamber to balance the inflow of ground water. The EPB machine is highly mechanized and can effectively advance a tunnel through a number of geologic conditions including unforeseen obstacles such as wood or concrete piles. It has an advantage over a Slurry Shield which functions in a similar fashion, but requires a large bentonite reclamation plant on the ground surface.

Ground displacement is closely related to the geometric configuration of the proposed tunnel and the quality of construction (extent of over excavation) that can be expected from the proposed construction technique. Each of the tunnel configurations were studied within the context of the King Street environment and a conceptual assessment indicated that the twin circular tunnels would be the most appropriate solution. The circular tunnels are compatible with the EPB Shield technology, they accommodate the alignment constraints and each of the dual tunnels is relatively small in cross section, thereby reducing the potential for large ground displacements.

Portal structures provide guideway transitions between the aerial and underground alignments. Standard tunneling techniques generally require a minimum overburden to preclude a cave-in scenario. At the portal locations the overburden requirements generally cannot be achieved, so construction usually reverts to the cut-and-cover method. This is the expected choice for King Street, and a traditional retained cut construction method is anticipated. The existing soil conditions and congested nature adjacent to the work site, encourage the selection of diaphragm wall construction. Diaphragm walls have the advantage of effectively controlling ground displacements thereby minimizing the potential of inducing structural building damage.

The proposed King Street Subway, as currently envisioned, contains two underground stations identified as King/Bethel, and King/Punchbowl stations. Internally, passenger stations are generally configured with platform orientations described as center, side or stacked. Selection of a station configuration is based on an array of parameters including geological constraints, functional/spatial design considerations, expandability, contextual considerations, right-of-way issues, and joint development potential.

The geotechnical boring logs taken along King Street indicate that the underlying coral is not continuous but very irregular with interbedded layers of soft silt and clay found in random unpredictable locations. These soft materials increase the potential of building damage during excavation of the stations and special care must be exercised when designing and erecting the temporary retaining system. The width of the King Street roadway is measured to be a minimum of 60 and 80 feet wide at the proposed King/Bethel and King/Punchbowl stations, respectively. A center platform station configuration has been proposed for both station locations, because it can be constructed within the available right-of-way, and because the center platform is deemed to be superior with regard to passenger circulation.

As with the line or running tunnels, the passenger stations are typically constructed using either mined or cut-and-cover techniques. Two mined-cavern excavation methods have been addressed as a part of this feasibility study. They are the New Austrian Tunneling Method (NATM) and a Jacked Pipe Arch method. Both methods may be feasible but did not appear favorable in light of the existing subsurface conditions. NATM is flawed by the relatively high water table and the risks of using compressed air in the voided coral. The jacked pipe arch scheme is complicated by the high water table and the existence of corals that may curtail the ability to jack the pipe sections. Therefore, a traditional cut-and-cover method was identified as the probable solution for construction of both passenger stations.

The costs were estimated assuming a concrete slurry wall as the earth retaining structure. A slurry wall has benefits in that it can be used to limit deflections of adjacent buildings much more effectively than other systems. Additionally, a slurry wall can be used as cut-off wall to isolate the station excavation so that dewatering efforts within the excavation will not draw down the surrounding water table, thereby causing additional settlements of adjacent buildings.

7.0 PASSENGER STATIONS

7.1 Introduction

Two underground stations are proposed within the *King Street Subway Study* area:

- King/Bethel
- King/Punchbowl

The two stations are projected to be among the highest patronage stations in the system; 34,400 and 13,500 daily patrons (2005 A.D.), respectively. Both stations are situated within the King Street right-of-way with the exception of their entrances. Their locations are partially constrained by alignment horizontal and vertical curve requirements.

The King Street Subway stations would provide service to the Downtown and Capital District areas. Both stations are a conventional configuration consisting of a center platform with mezzanines. The mezzanines permit a degree of flexibility in locating station entrances and in providing connections to adjacent buildings. Both stations are provided with multiple entrances to enhance patron accessibility.

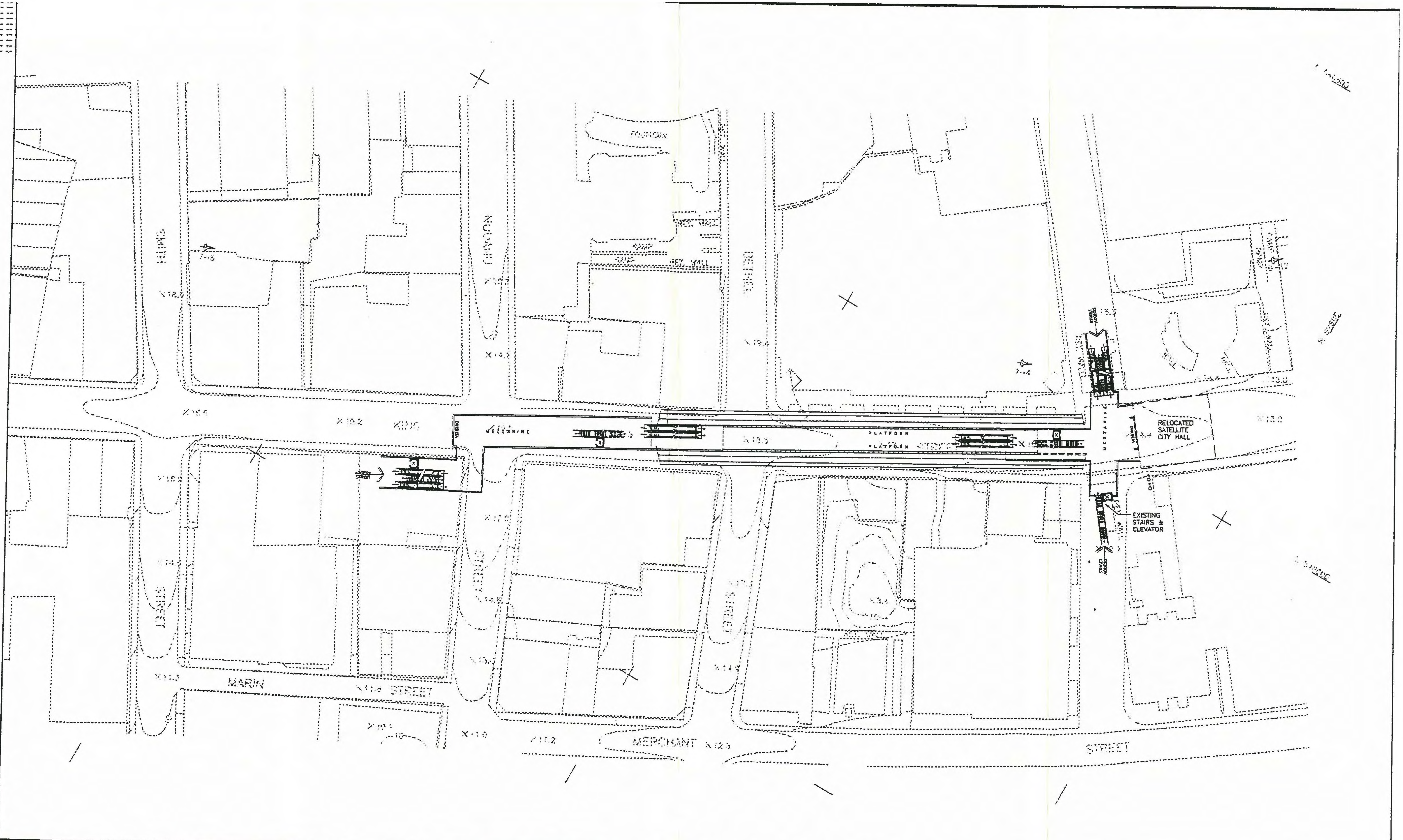
The vertical circulation elements of grade-separated stations can vary depending on the projected patronage, vertical separation between entry level and platform level, code requirements, and a transit authority's design policies. Some systems only provide escalators in the up direction, particularly in low-patronage stations. Given the high projected patronage for the King Street stations, escalators for both the up and down directions are proposed.

The aerial stations of the rapid transit system are configured with 190-foot-long platforms that are expandable to 280 feet in the future. Given the inherent construction- and geometric-related issues associated with extending platforms of underground stations, the King Street Subway stations would have to be constructed to their ultimate platform length of 280 feet.

7.2 King/Bethel Station

The platform for the King/Bethel Station would be located between Bethel and Fort Street (Sketch 7.1). Entrances at both ends of the station are provided. These entrances would provide vertical circulation down to a mezzanine level where the fare vending equipment would be located. Locating fare vending and related station functional equipment at mezzanine level minimizes the spatial requirements at grade level.

The Ewa entrance would relocated in an existing building on the Ewa/makai corner of King and Nuuanu streets. This entrance would be equipped with two escalators, stairs, and an elevator. At the Koko Head-end station access would be provided on the Fort Street Mall through the existing stairs and elevator mauka and makai of King Street that currently provide access to the satellite City Hall. This facility would have to be relocated immediately Koko Head to



REV	DATE	DESCRIPTION	BY	APP

Designed by:
Drawn by:
Checked by:
Approved by:

THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION.

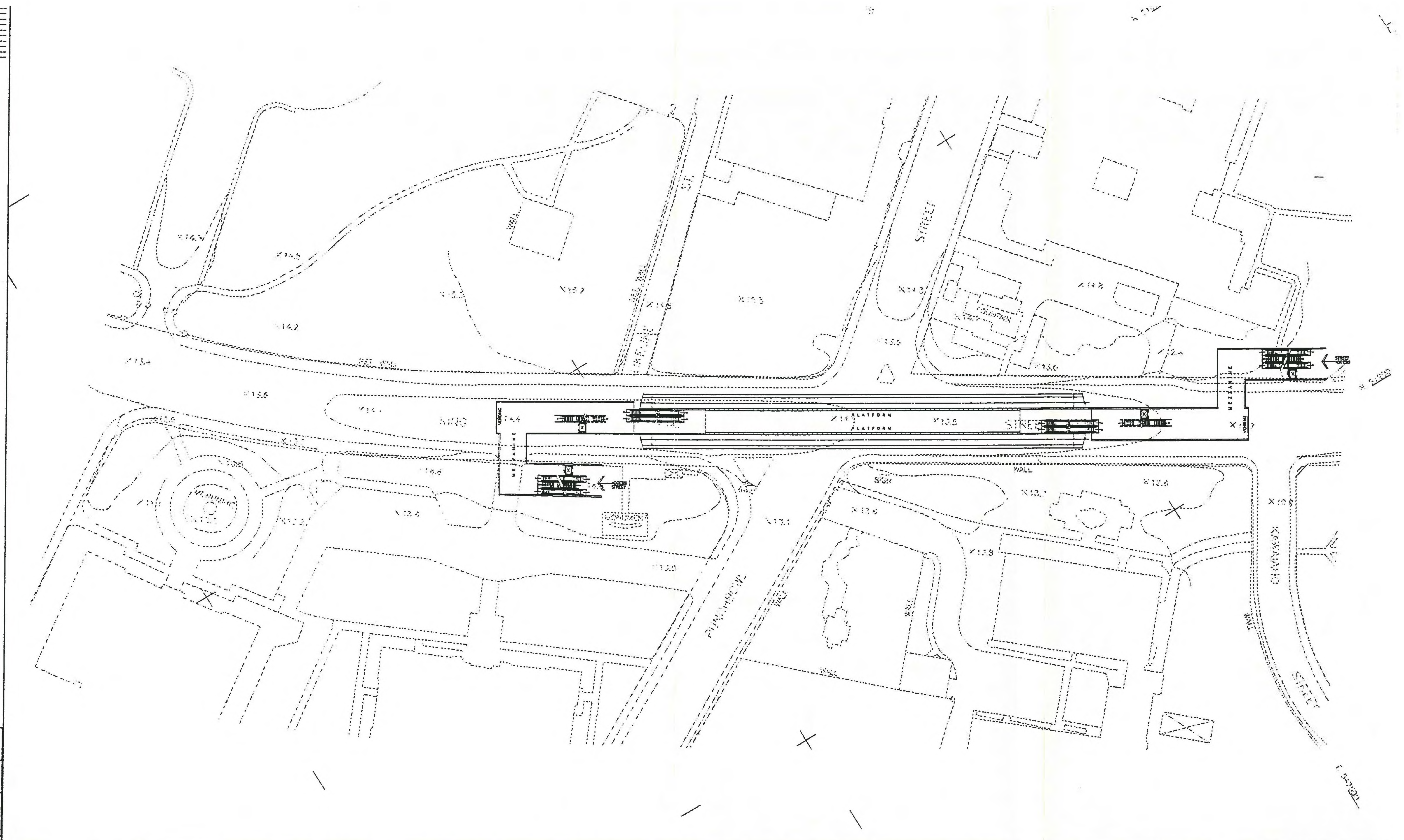
DEPARTMENT OF TRANSPORTATION SERVICES
HONOLULU RAPID TRANSIT PROGRAM

SUBMITTED: ____________

APPROVED: ____________

SKETCH 7.1
KING/BETHEL STATION

CONTRACT NO.
DRAWING NO. AAD6300
REV.
SHEET NO.
SCALE 1"=40'
DATE FEB.25,1992



REV	DATE	DESCRIPTION	BY	APP.

THIS WORK WAS PREPARED BY ME OR UNDER MY SUPERVISION.

DEPARTMENT OF TRANSPORTATION SERVICES
HONOLULU RAPID TRANSIT PROGRAM

SUBMITTED:

APPROVED:

SKETCH 7.2

KING/PUNCHBOWL STATION

CONTRACT NO.

DRAWING NO. AAD6600

REV.

SHEET NO.

SCALE 1"=40'

DATE FEB.25,1992

8.0 PATRONAGE PROJECTIONS

Ridership estimates for the King Street alignment were prepared using the forecasting model developed for the Preliminary Engineering phase of the Honolulu Rapid Transit Program. The ridership estimates for the No-Build, TSM and amended LPA alternatives remain the same as those that were used in the SDEIS because the alternative systems are not changed.

Systemwide ridership is projected to increase by approximately 3,500 passengers per day over the amended LPA if the proposed alignment along Nimitz Highway and Pohukaina Street is shifted to King Street. This is a 1.1% increase in systemwide ridership.

The primary reason for the difference in patronage estimates is the travel time savings gained by shifting the alignment two to three blocks mauka and replacing the five stations along the Pohukaina alignment with two stations along the King Street alignment between the Honolulu Community College Station and the Neal Blaisdell Center Station. This alignment change produces a line that is approximately one-third of a mile shorter and takes almost three minutes less to traverse.

The number of passengers using the stations along the segment affected by the alignment change is almost identical for the two alternatives. In the LPA alternative, there will be a projected 60,300 daily boardings and alightings at the seven stations from Honolulu Community College to Neal Blaisdell Center. This number is compared to the projected 60,400 daily boardings and alightings at the four stations along the same segment of the King Street alignment.

In the LPA alternative, the peak one-way Koko Head-bound hourly volume is projected to be 8,500 passengers between the Kaaahi Station and the Nimitz/Smith Station. This compares to a peak volume of 8,800 AM peak-hour passengers between the Honolulu Community College and the King/Bethel Station in the King Street alternative. This 3% difference in peak load point would require a corresponding increase in the peak-period service in order to carry the added passenger load, which can be accomplished by reducing the headway time between trains. This 3% headway decrease would be more than offset by the 8-9% decrease in the round trip travel time for the shorter King Street alignment, resulting in the need for approximately 5% fewer fixed guideway vehicles in the King Street alignment alternative.

9.0 ENVIRONMENTAL IMPACTS

9.1 Introduction

This section summarizes the potential environmental impacts caused by cut-and-cover and bored-tunnel construction and construction operations. The primary environmental impacts discussed in this section will be those to traffic, noise and vibration levels, visual quality, air quality, historic properties, archaeological sites, and parklands, and those that cause business disruption and displacement.

9.2 Short-Term Impacts During Construction

9.2.1 Traffic

Traffic impacts during the construction of the King Street tunnel are of serious concern. Construction on portions of Kings Street would require rerouting up to five lanes of traffic. Street sections at stations and portal locations, including some cross streets at intersections, would be constricted for months during cut-and-cover construction. General traffic on the affected cross streets in the vicinity of the South King/Punchbowl intersection would require rerouting or temporary lane closures during the construction of the King/Punchbowl Station. Additional congestion and travel delays on adjacent streets would occur. To minimize street closure impacts, should they be necessary, not all streets would be closed at the same time. These closures would, however, constrict traffic in the area and force drivers to look for alternative routes. Streets and/or lanes would be reopened as soon as traffic decks were constructed over the cut-and-cover construction areas.

In subway construction areas where bored-tunnel techniques were used, the disruption to local traffic and circulation and the impacts on businesses, especially small businesses, would be less severe than areas adjacent to the cut-and-cover construction.

Pedestrian access would be maintained to all properties along the alignment throughout construction although the pedestrian environment would be disrupted by dust and construction noise. Access would be less convenient and temporary sidewalks might be required.

A detailed Maintenance-of-Traffic Plan would be prepared with a set of transit and general traffic rerouting schemes for each tunnel construction phase. The plan would address maintenance of traffic, bus service, and pedestrian activity while allowing the delineation of a construction area. The rerouting of transit and general traffic would cause varying degrees of congestion depending on the rerouting schemes. Bus stops currently within the construction area would be relocated during construction depending on the scheme selected.

Construction traffic routes would be specifically identified in the plan and would be selected to minimize traffic and other impacts on nearby residences and businesses. For example, truck traffic could be limited to off-peak hours and to streets not utilized for bus rerouting.

An aggressive public information program alerting motorists and commuters to delays and rerouting would be included in the plan. During special events, construction activity could be modified, if needed, to minimize the effect on the event.

Construction vehicles would also increase congestion in the construction area. Construction traffic involves a wide variety of vehicles, including additional cars and small and large trucks used for the delivery of major pieces of equipment and for hauling away construction debris and excavated materials. The heaviest area of construction traffic would be in the vicinity of the station and portal construction areas. The Maintenance-of-Traffic Plan would also identify truck routes that would minimize traffic in nearby residential and business areas.

9.2.2 Business Disruption

Cut-and-cover construction at station and portal sites could cause significant disruptions to nearby businesses. Temporary access to the affected businesses without alternative street access would be maintained. Businesses near sites of bored-tunnel construction would experience some disruptions due to alternative traffic patterns and delays.

9.2.3 Noise and Vibration

Construction noise levels would be an adverse impact on nearby residences, office buildings, and other sensitive receptors. Noise levels would be the highest during street-level cut-and-cover construction at station locations. Construction machinery would typically operate in direct line of sight with buildings adjacent to the alignment until the excavation is deep enough that the excavation walls would act as noise barriers. Noise generated by the tunnel boring machine in subway areas would be effectively muffled by the ground between the tunnel and the surface and would not significantly affect the surrounding offices and residences.

Rerouted traffic could cause some increase in noise levels on streets in the vicinity. The construction contractor would be required to comply with the Community Noise Control requirements of the State of Hawaii.

The tunnel boring machine moving along could create groundborne vibration that could cause cracks, make plaster fall, and loosen paint. Specific structures and buildings adjacent to construction operations would require monitoring during construction. A preventive program would be established to minimize the impacts of vibration during construction.

9.2.4 Visual

On-site storage of equipment and materials would add some temporary visual clutter to the King Street area. Most construction would occur below grade along King Street, except in the areas of cut-and-cover construction at station and portal locations.

9.2.5 Air Quality

Exhaust emissions from heavy-duty construction trucks and equipment for replacing pavement and excavation would cause direct air quality impacts. Uncovered trucks and soils raised by construction vehicle tires and frames could deposit substantial dust onto adjacent streets. Contractors would be required to cover all trucks carrying soils from the tunnel excavation.

Increases in traffic congestion near the construction site would indirectly affect air quality. Closure of traffic lanes would interrupt traffic patterns, and thus reduce traffic speeds. These slower speeds would increase vehicle emissions.

9.2.6 Historic/Archaeological

The King Street Subway alignment is not expected to affect any historic buildings; however, the access to the King/Bethel Station would require displacement of one building within the Chinatown Historic District at the corner of Nuuanu Avenue and King Street. This property would be subject to both Section 4(f) and Section 106. Mitigation for the project includes measures to ensure that the integrity of all structures on or adjacent to the alignment remain.

The King Street Subway traverses three historic districts: Chinatown Historic District, Merchant Street Historic District and the Hawaii Capital Historic District. The McCandless Building, adjacent to the King Street Subway alignment, lies within the Merchant Street Historic District. Historic sites along the King Street subway alignment in the Hawaii Capital Historic District are the Iolani Palace and bandstand, Old Royal Tomb, Kamehameha Statue, Territorial Building, Judiciary Building, Hawaii State Library, Honolulu Hale and Annex, Mission Houses, Kawaiahao Church, the Hawaiian Electric Company Building (HECO), and the Post Office and Customs Building. Outside the Hawaii Capital Historic District, adjacent to the alignment, is the Advertiser Building. The Advertiser Building has been determined to be eligible for the National Register of Historic Places.

In addition, a determination of eligibility for the National Register of Historic Places would be required for two properties along King Street, if the King Street Subway alignment would go forward. The first building is the First Hawaiian Bank Building at Bishop Street. The second property is bound by Richards Street and the Hawaii Capital Historic District. It is part of the HECO Building block that includes the Wolter Building, the Arcade Building, the old HECO building (not encompassed within the historic district). All historic properties would be subject to Section 106 review.

A tunnel requires extensive excavation. It is therefore anticipated that some sites of archaeological value would be uncovered. Additional studies, including a testing and monitoring program, would be required later in the design phase. The monitoring phase would include a burial disinterment program to be negotiated as part of the 106 review.

9.2.7 Parklands

Three parks have been identified along the King Street alternative: Fort Street Mall Park, Tamarind Park, and the Iolani Palace State Monument. The King Street Subway alignment will not impact these parklands.

9.3 Cut-and-Cover Construction

Generally, cut-and-cover construction would have more significant traffic impacts than bored-tunnel construction because greater portions of the street would be closed for longer periods of time. In addition, the potential exists for additional displacements as the subway alignment enters King Street Koko Head of the Nuuanu Stream. These displacements would affect structures within the Chinatown Historic District, subject to both Sections 4(f) and 106.

9.4 Operational Impacts

9.4.1 Traffic

There are no operational impacts associated with the King Street Subway Alternative.

9.4.2 Business Displacement and Relocation

Generally, the displacements, as a result of the King Street Subway Alternative, would be greatest in the portal areas. The Ewa portal would displace approximately three businesses (approximately 35,666 square feet) on Kaaahi Street. The largest of these businesses is the Nishimoto Trading Company, a wholesale Oriental food distributor, with approximately 60 employees. The remaining two companies are warehouse distribution businesses, employing approximately six workers each. The Koko Head portal, between Kapiolani Boulevard and Waimanu Street, would displace approximately 21 businesses located in the three buildings; however, many of these businesses are in the process of relocating as the result of other development. The King/Bethel Station would displace the five businesses in the building on the Ewa/makai corner of Nuuanu and King streets.

Since the project is proposed to use federal funds, it is subject to 49 CFR, Part 24, Uniform Relocation Assistance and Real Property Acquisition for Federal and Federally Assisted Programs. Probable relocation benefits for the businesses displaced are summarized in the following paragraph.

Moving expenses would be reimbursed for all actual and reasonable expenses incurred in moving, whether by professional mover or by the displacee. Proof of expenses would be required. Alternatively, in lieu of this reimbursement, businesses that meet certain qualifications may elect an optional payment, which would be an amount equal to the average annual net earnings, before taxes, of the business for the last two tax years, not less than $1,000 nor more than $20,000. Non-profit organizations may elect for a fixed payment, equal to the average net income after expenses for 2 years, not to exceed $20,000, but at a minimum of $2,500. The displacing agency is required to assist the displacee of a non-profit organization in locating a suitable new location. This requirement does not necessitate that the displacing agency find a new location for the displacee but rather assist the displacee as best it can.

9.4.3 Noise and Vibration

Although adverse airborne noise impacts would be eliminated, a potential exists for groundborne noise and vibration impacts to buildings along the alignment. The noise of passing trains may be audible in small buildings along the alignment but would not likely be objectionable because the downtown area is already subjected to high noise levels from street traffic.

The required separation distance to avoid impact is dependent on several factors including local soil conditions, vibrational characteristics of the transit vehicle, train operating speed, the rail or guideway roughness and the type of building affected. Based on the best information available, there should be no noticeable impact. However, if ground-borne vibration or ground-borne noise along the subway alignment is determined to an adverse impact based on additional information, proposed, mitigation may include one or more of the following: floating slab, ballast mat, soft resilient fasteners or resiliently supported ties.

9.4.4 Visual

The King Street Subway would not have any significant visual impacts. The design of station entrances and portals would be integrated into the context of the surrounding areas and subject to design review as part of the Chinatown Historic and Hawaii Capital Special Districts.

9.4.5 Air Quality

There are no operational impacts on the air quality within the King Street Subway vicinity.

9.4.6 Historic/Archaeological

Design of the station entrances would reflect the architecture and character of Chinatown Historic District and Hawaii Capital Historic District minimizing impacts caused by the proximity of the transit project. Once construction is completed, there would be no additional impacts to the archaeological resources.

9.4.7 Parklands

There are no operational impacts on parkland resources associated with the King Street Subway Alternative.

9.5 Conclusion

The construction impacts would be similar for the King Street Subway and Hotel Street Subway alternatives. The greatest differences would occur in the impacts to traffic, historic properties, and parklands. The construction traffic impacts would be greater with the King Street Subway since much of the vehicular traffic would have to be rerouted to other streets. Currently, portions of King Street accommodate five lanes of traffic. Hotel Street is currently a bus-only mall; with that alternative bus traffic would be rerouted to King and Beretania streets and only cross traffic and local traffic would have to be maintained.

Both alternatives pass through several historic districts and would be in the vicinity of several historic buildings. The proposed Hotel Street Subway would have an adverse affect on an historic property, the Nuuanu Bridge; the proposed King Street Subway would result in the demolition of a building within the Chinatown Historic District. The Nuuanu Bridge would be demolished and rebuilt. The historic building would be permanently displaced by a station access with the historic district. The Hotel Street Subway would also require a construction easement at the Chinatown Gateway Plaza.

The long-term impacts would also be similar for the King Street Subway and Hotel Street Subway alternatives. The greatest differences would occur in the impacts to business displacement and traffic. The long-term impacts for traffic would be greatest with the Hotel Street Subway alignment since the bus traffic would be permanently rerouted from the Mall. The Hotel Street Subway business displacements (26 to 66 businesses) would generally be greater than the business displacements (29 businesses) for the King Street Subway alternative. A majority of the business displacement differences occur in the downtown area.

10.0 ENVIRONMENTAL PLANNING SCHEDULE

The selection of the King Street Subway alternative as part of a revised "amended LPA" would have a significant effect on the deadlines currently established for the project. The choice of the King Street Subway alignment would require the preparation of a supplemental draft environmental impact statement (SDEIS) and subsequent final environmental impact statement (FEIS). The production of a more detailed project description, engineering studies, and environmental studies could add a total of fourteen additional months to the project schedule.

11.0 CONSTRUCTION COST ESTIMATE

11.1 Introduction

An order of magnitude cost estimate has been prepared for the King Street Subway. The boundary limits of the estimate start in the Ewa direction where the aerial structure ends and terminates in the Koko Head direction where the aerial structure begins.

11.2 Definition Documents

The following documents were used in the preparation of these estimates:

- Draft King Street Subway Plan and Profile Drawings K.AL.A.001 through K.AL.A.004.

11.3 Scope

The estimate includes all costs for the proposed King Street Subway procurement contract and other costs to the City so that a valid comparison with the originally proposed Hotel Street subway may be reached. The other costs to the City include station finishes, private utilities, landscaping, right-of-way, engineering and management. Costs not included are those associated with System Vendor procurements.

This estimate specifically includes the following items:

- Demolition: Includes demolition of specific buildings and removal of the debris.

- Utility Relocation: Complete cost of relocating utilities has been included. Cost was factored using the Hotel Street estimate as the basis.

- Street Modifications: Included are street, curb, and sidewalk demolition and reconstruction. Cost was factored using the Hotel Street estimate as the basis.

- Underpinning: Cost of underpinning includes preconstruction grouting as well as conventional underpinning with driven piles and/or jack piles. Cost was factored using Hotel Street estimate as the basis.

- Subway: Cost of subway includes excavation, preexcavation stabilization where required, and structure. Tunneling generally assumes use of an earth pressure balance (EPB) tunnel boring machine. Cut-and-cover construction generally assumes slurry-wall construction. Also included are costs for street decking and traffic maintenance.

- Stations: Cost of stations includes excavation, preexcavation stabilization where required, structure, and all station finish work, including escalators and elevators. All stations are constructed using cut-and-cover construction generally assuming slurry-wall construction.

- Landscaping: Included is an allowance for landscaping at the subway portals only.

- Engineering and Management: Included are engineering supervision and construction management by the General Engineering Consultant (GEC) and engineering and administration by the City. Excluded are preliminary engineering, and preoperating expenses by the City. Preoperating expenses refer to the cost of maintaining and operating a facility during the period of time between completion of construction and initiation of revenue service.

- Contingency: An allowance to cover design development and unforseen conditions/uncertainties (i.e., geotechnical issues, etc.) that are recognized in the very approximate estimating methods used at this stage of the project.

Cost Exclusions:

1. Systemwide elements including vehicles, trucks, signals, etc.

2. Preliminary engineering

3. Owner (City) cost for financing and preoperating expenses

4. Operating costs

5. Project Reserve for change orders and scope enhancements.

11.4 Pricing and Escalation

Pricing of all construction elements includes labor, burden, construction equipment usage, material, permanent equipment, contractors' overhead and profit, and design by the turnkey design/construct contractor. Current pricing quotes were obtained for selected materials.

This estimate is considered to be in June 1991 dollars. No escalation is included.

11.5 Cost Breakdown

A summary of the costs for the King Street Subway is on the following table. Also included for comparison purposes are tabulations for the Hotel Street Current Working Estimate, the Hotel Street Subway Study Report Estimate, and an analysis for utilizing cut-and-cover construction for King Street.

ICF KAISER ENGINEERS, INC.
JOB NO. 91184 (REV 0)

DATE: 18-Mar-92

COMPARISON OF SUBWAY ALTERNATIVES

(Cost Unit or Multiplier - x 1000)

DESCRIPTION	UNIT	HOTEL STREET CWE QUANTITY	HOTEL STREET CWE COST	HOTEL STREET 7/91 QUANTITY	HOTEL STREET 7/91 COST	KING STREET (MINED) QUANTITY	KING STREET (MINED) COST	KING ST.(CUT & COVER) QUANTITY	KING ST.(CUT & COVER) COST
SYSTEM DATA:									
ROUTE LENGTH	RF	8,070		7,945		8,100		8,100	
TRACK LENGTH	TF	16,140		15,890		16,200		16,200	
NUMBER OF STATIONS	EA	3		3		2		2	
CONSTRUCTION COSTS:									
SITE MODIFICATIONS									
DEMOLITION	LS			1	4,217	1	4,401	1	4,401
UTILITY RELOCATION	RF			7,945	13,135	8,100	8,318	8,100	11,502
STREET MODIFICATIONS	SY			6,066	607	6,066	607	6,066	607
UNDERPINNING	LS			1	7,875	1	6,300	1	6,300
GDWAY RETAINED CUT	RF			883	5,783	655	5,240	655	5,240
SUB-CUT & COVER DBL BOX	RF			1,212	29,199	1,015	23,239	6,685	99,700
TUNNEL	RF			4,050	69,936	5,670	79,641	0	0
STATIONS SUBWAY									
SIDE PLAT. W/ MEZZ	EA			0	0	0	0	2	72,400
CTR PLAT. W/ MEZZ	EA			1	36,638	2	66,300	0	0
STACKED (W/TUNNEL)	EA			2	65,150	0	0	0	0
JET GROUTING	LS			1	9,069	1	9,069	1	9,069
Subtotal CONSTRUCTION COSTS:					$241,609		$203,115		$209,219
CONTINGENCY					72,483		60,935		62,766
TOTAL CONSTRUCTION COSTS:			$322,969		$314,092		$264,050		$271,985
OTHER COSTS TO THE CITY:									
HOTEL STREET MALL	SF		8,334	119,050	8,833	N/R		N/R	
LANDSCAPING	LS	1	400	1	1,346	1	400	1	400
STATION FINISHES	LS	1	29,532	1	17,500	1	17,314	1	17,314
PRIVATE UTILITIES	LS	1	8,781	1	3,941	1	2,495	1	3,451
RIGHT OF WAY & AGREEMENTS	LS	1	73,572	1	70,734	1	57,675	1	57,675
Subtotal OTHER COSTS TO THE CITY:			$120,619		$102,354		$77,884		$78,840
CONTINGENCY			0		30,706		23,365		23,652
TOTAL OTHER COSTS TO THE CITY:			$120,619		$133,060		$101,250		$102,491
TOTAL CONSTR & OTHER COSTS			$443,588		$447,152		$365,299		$374,476
ENGR & MGMT (GEC + OWNER COST)			25286		44,715		36,530		37,448
ESCALATION:									
ESCALATION			0		0		0		0
PROJECT RESERVE:									
PROJECT RESERVE			39,593		0		0		0
TOTAL:			$508,467		$491,867		$401,829		$411,924

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12.0 CONCLUSION

The objective of the King Street Alignment Study was to prepare a conceptual-level design for an alternative subway alignment through downtown Honolulu that would satisfy the transit system design requirements, and reduce the cost of construction relative to the originally proposed Hotel Street Subway.

The proposed King Street Subway alignment would begin at the originally planned Hotel Street Subway portal near Kaaahi Street and generally follow King Street through downtown Honolulu. The proposed King Street Subway would intersect with the original Hotel Street alignment near Kapiolani Boulevard and South King Street and terminate at the previously proposed Hotel Street Subway portal near Dreier Street. Two passenger stations are planned for the King Street Subway. They are designated as the King/Bethel and King/Punchbowl stations, which is descriptive of their respective locations.

The long-term environmental impacts would be similar for the Hotel Street Subway and King Street Subway alternatives. The greatest differences would occur in the impacts to business displacement and traffic. The long-term impacts for traffic would be greatest with the Hotel Street Subway alignment since the bus traffic would be permanently rerouted from the Mall. The Hotel Street Subway business displacements (26 to 66 businesses) would generally be greater than the business displacements (29 businesses) for the King Street Subway alternative.

An order-of-magnitude cost estimate has been prepared for the *King Street Subway Study*. The construction cost estimate includes expenditures pertaining to demolition, utility relocation, street modifications, underpinning, subway and passenger station facilities, landscaping, final engineering, project management, and a contingency allowance. The estimated cost is a total program cost, including insurance, administration, and all other City expenses, and is comparable to the "TOTAL" amount cited in the *Hotel Street Subway Study Report*, dated July, 1991.

The estimated cost to build the King Street Subway is $402 million in calendar-year 1991 dollars, which is a cost reduction of approximately 18 percent relative to the initially planned Hotel Street Subway. A conceptual-level cost estimate was also prepared considering cut-and-cover construction for the entire length of the King Street Subway. Utilizing this construction method for the King Street alignment actually increased the subway expenditure to $412 million. This increase is attributed to the cost of utility relocation, temporary decking and maintenance of traffic on King Street.

The proposed fixed guideway rapid transit system, inclusive of the Nimitz Option, is scheduled to be completed and open to revenue service by 1997. Design and construction of a King Street Subway segment would take approximately three years. If the procurement process for a subway contract was initiated by June of 1992, the availability of the transit system would be delayed by approximately one year.