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HAL McCULLOUGH
AUTUMN 1989

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HBMP
HUNTINGTON BEACH MUNICIPAL PIER

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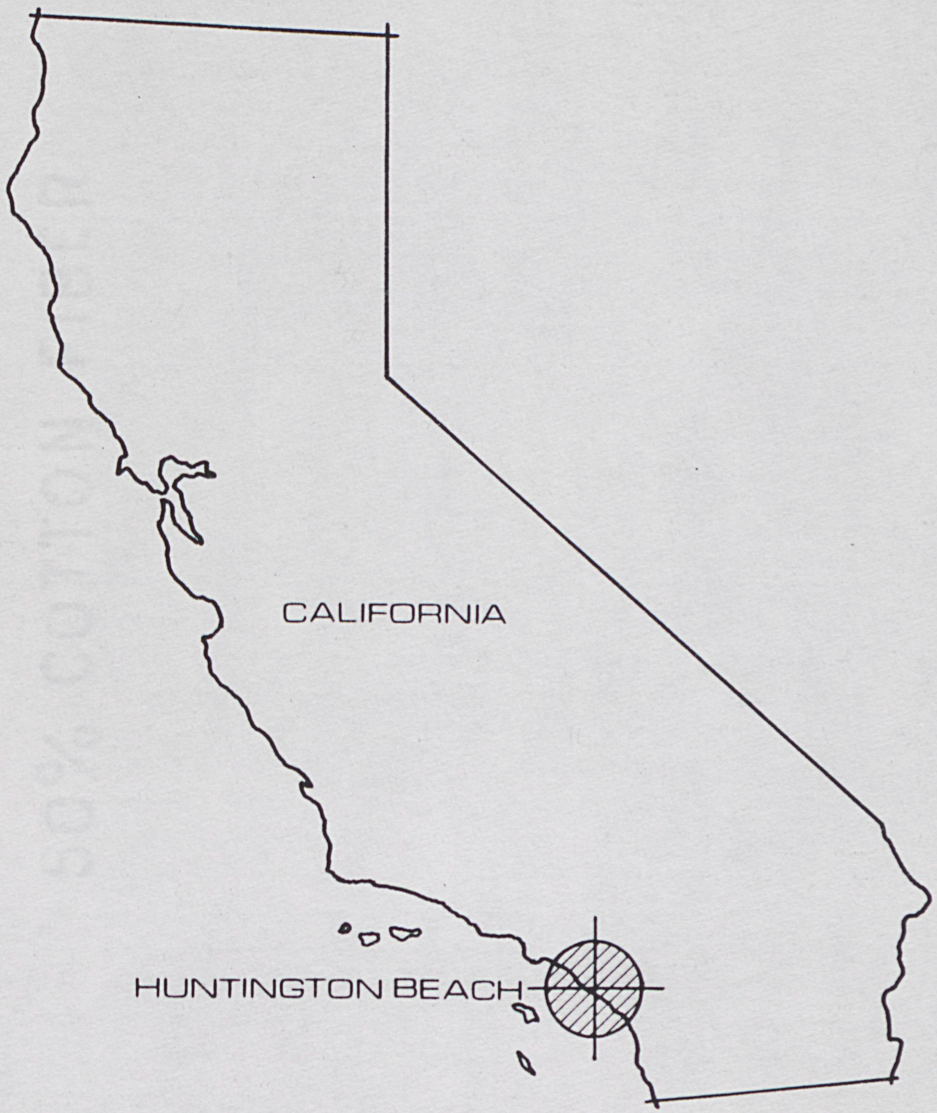
# INTRODUCTION

MY THESIS PROJECT IS A SITE SPECIFIC ONE WHICH EVOLVED OUT OF A NEED TO REPLACE A WELL KNOWN AND LOVED, BUT STRUCTURALLY UNSAFE, LANDMARK; THE MUNICIPAL PIER OF HUNTINGTON BEACH, CALIFORNIA. UNLIKE OTHER COASTAL COMMUNITIES IN CALIFORNIA THAT HAVE BEEN REBUILT AND TRANSFORMED THROUGH COMMERCIALIZATION, HUNTINGTON BEACH HAS REMAINED RELATIVELY UNTOUCHED OVER THE YEARS AND STILL RETAINS ITS REPUTATION AS THE 'SURFING CAPITAL OF THE WORLD.'

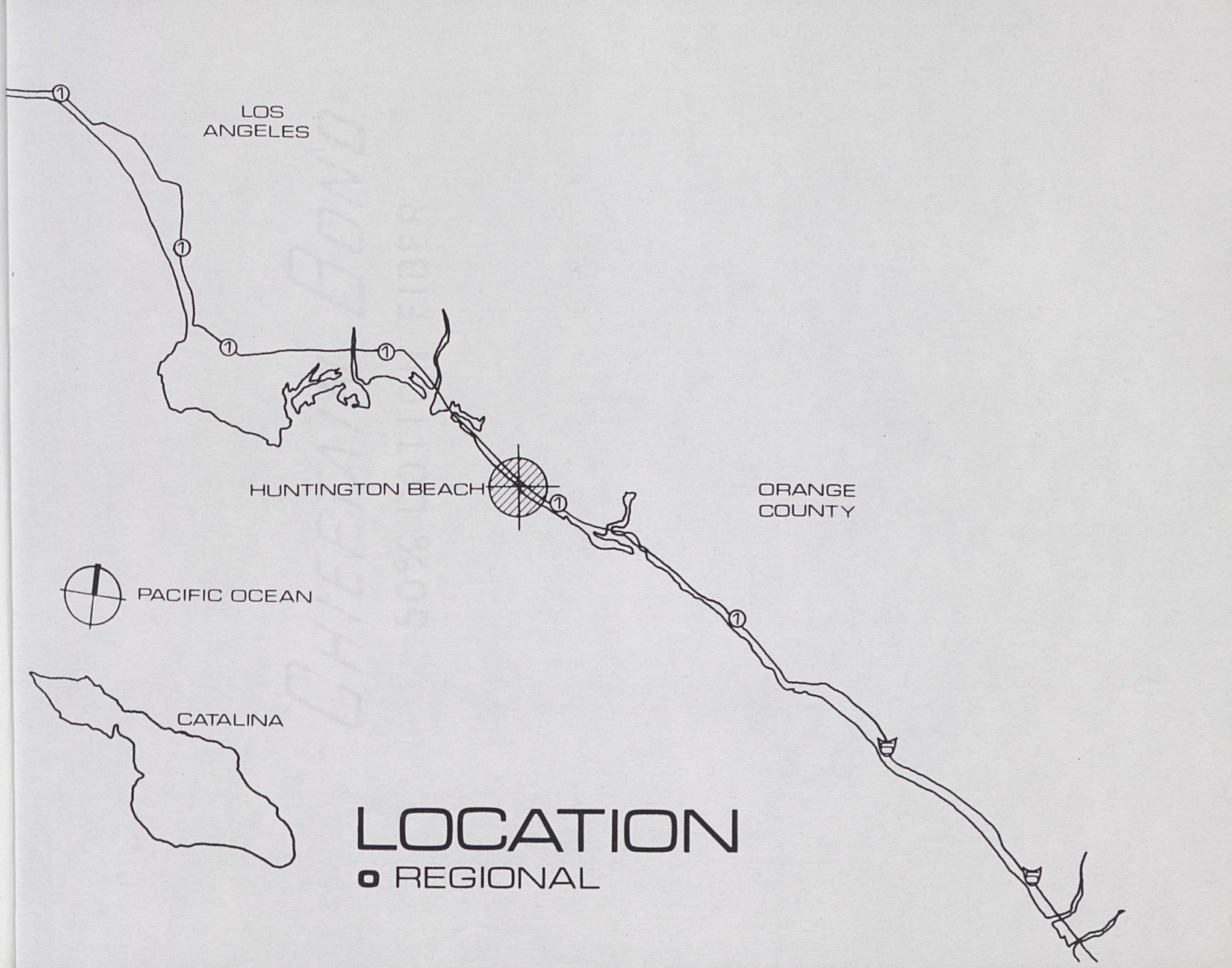
THE EXISTING CONCRETE PIER, ORIGINALLY CONSTRUCTED IN 1914 TO ALIGN WITH MAIN STREET, PLAYED A MAJOR ROLE AS A COMMUNITY FOCAL POINT UNTIL IT WAS ABRUPTLY CLOSED ON JULY 12, 1988. THE PIER CLOSURE CREATED AN IMMEDIATE VOID FELT BY MANY, INCLUDING MYSELF, WHO HAD USED THE PIER FOR RECREATIONAL AS WELL AS SOCIAL PURPOSES.

THE STATE OF DETERIORATION IN THE EXISTING PIER IS SO WIDESPREAD AND EXTENSIVE THAT IT IS CONSIDERED TO BE BEYOND REASONABLE REPAIR. THE CHALLENGE OF MY THESIS; THEN, IS TO DESIGN A NEW STRUCTURE THAT IS APPROPRIATE FOR THE SETTING OF HUNTINGTON BEACH AND FOR THE USERS IT WILL SERVE.




# LOCATION

o STATE


LOS
ANGELES
HUNTINGTON BEACH
ORANGE
COUNTY
PACIFIC OCEAN
CATALINA
LOCATION
REGIONAL

# THESIS STATEMENT

THE SCOPE OF MY THESIS PROJECT CONSISTS OF A LINEAR STRUCTURE, THE PIER ITSELF, INTERRUPTED BY A SERIES OF PROGRAMMATIC EVENTS. THE PROPOSED STRUCTURE WILL NOT ONLY EXTEND WESTWARD INTO THE PACIFIC OCEAN; BUT, ALSO EASTWARD ACROSS PACIFIC COAST HIGHWAY AND DOWN MAIN STREET. THIS STRUCTURAL INFLUENCE ON MAIN STREET WILL BE IN THE FORM OF STREET FACILITIES AND FIXTURES. MY PRIMARY CONCERN FOR THE PROJECT IS TWOFOLD:

1. STRUCTURAL SAFETY AND ADHERENCE TO MARINE ENVIRONMENTAL DESIGN CRITERIA.
2. TO SURPASS THE PURELY PRAGMATIC REQUIREMENTS AND CREATE A USER SENSITIVE STRUCTURE THAT IS UNIQUE TO AND IDENTIFIED WITH HUNTINGTON BEACH, CALIFORNIA.

# GOALS

THERE ARE FOUR MAIN GOALS WHICH I WOULD LIKE TO ACHIEVE IN MY PROJECT:

1. TO INTEGRATE, IN A SENSITIVE MANNER, NEW STRUCTURE INTO THE EXISTING FABRIC AND CHARACTER OF HUNTINGTON BEACH.

2. REFER TO, BUT RE-EVALUATE, THE CONFIGURATION OF THE EXISTING PIER IN THE DESIGN OF THE NEW STRUCTURE.

3. MAINTAIN THE NEW PIER AS CHIEFLY RECREATIONAL; CATERING SPECIFICALLY TO FISHING, AQUATIC SPORTS, AND OCEAN OBSERVATION.

4. CREATE A STRUCTURE THAT WILL POSSESS AN ICONOGRAPHIC QUALITY AND ACT AS A LANDMARK FOR HUNTINGTON BEACH.

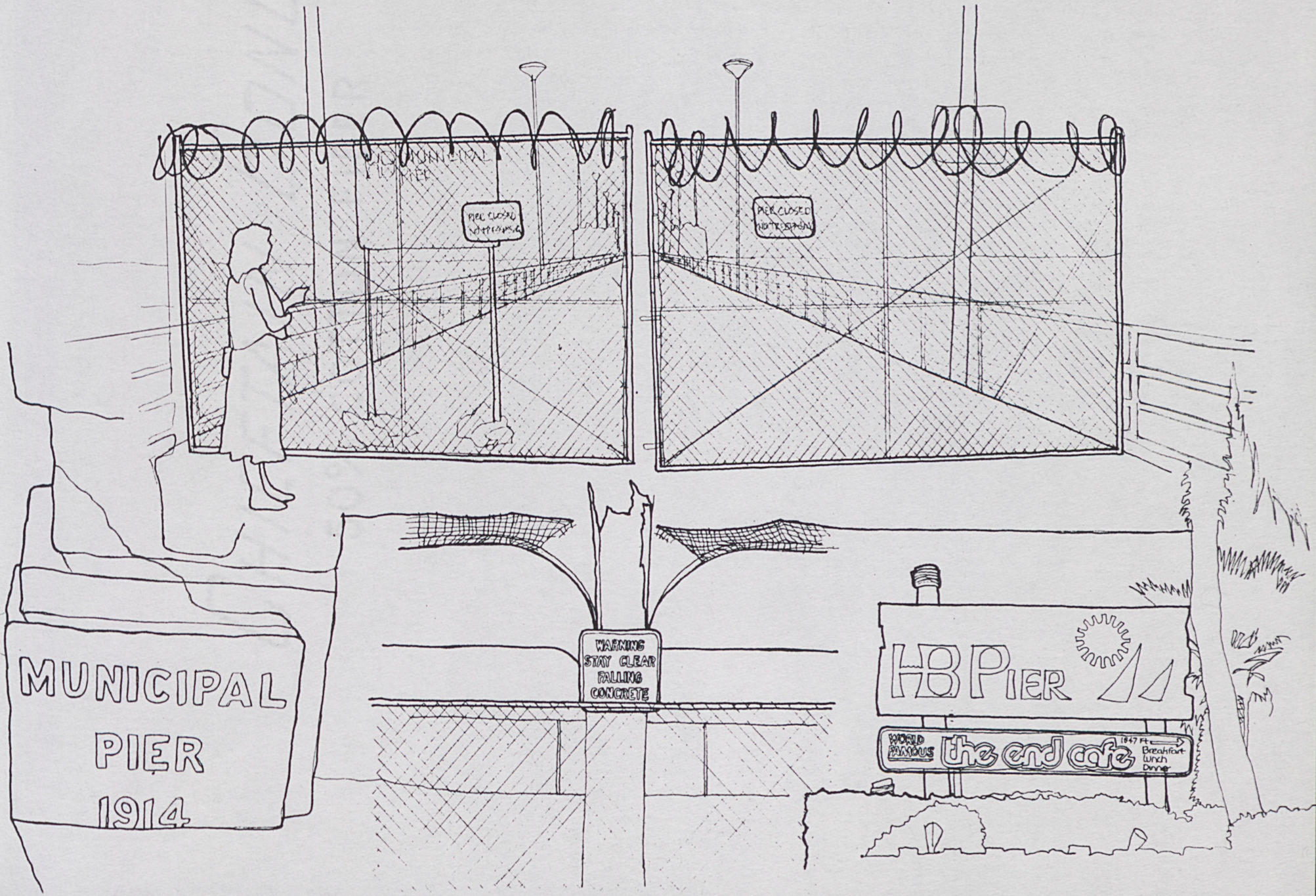
# PIER HISTORY

1902 ORIGINALLY CONSTRUCTED OF UNCREOSOTED ROUGH PINE, 1,000 FEET LONG.
1910 PILINGS PRACTICALLY DESTROYED BY BARNACLES.
1911 VOTERS PASSED A $70,000 BOND ISSUE TO REBUILD THE PIER IN REINFORCED CONCRETE.
1914 PIER COMPLETED, 1314 FEET LONG.
1931 A 500 FOOT WOODEN EXTENSION ADDED MAINLY FOR FISHERMEN AND BOAT OPERATORS.
1939 WOODEN STRUCTURE DESTROYED BY A CHUBASCO (MEXICAN HURRICANE).
1940 WOODEN STRUCTURE REBUILT, 1821 FEET TOTAL LENGTH.
1983 PIERHEAD SEVERELY DAMAGED IN WINTER STORM.
1984-1985 WOODEN PIERHEAD REPAIRED AND STRENGTHENED, RESTAURANT (TWO-STORIES) BUILT ON PIERHEAD.
1988 STORM ON JANUARY 17-18 DESTROYED WOODEN PIERHEAD AND RESTAURANT.
1988 PIER CLOSED TO PUBLIC ON JULY 12.

# CONTEXT & USERS

AS STATED IN THE INTRODUCTION, HUNTINGTON BEACH IS UNLIKE THE MANY COASTAL COMMUNITIES OF SOUTHERN CALIFORNIA THAT HAVE LOST THEIR ORIGINAL CHARACTER THROUGH REDEVELOPMENT AND COMMERCIALIZATION. THE INTENT OF THE FOLLOWING DRAWINGS IS TO CAPTURE THE SPIRIT AND PEOPLE OF HUNTINGTON BEACH AS THEY EXIST TODAY.

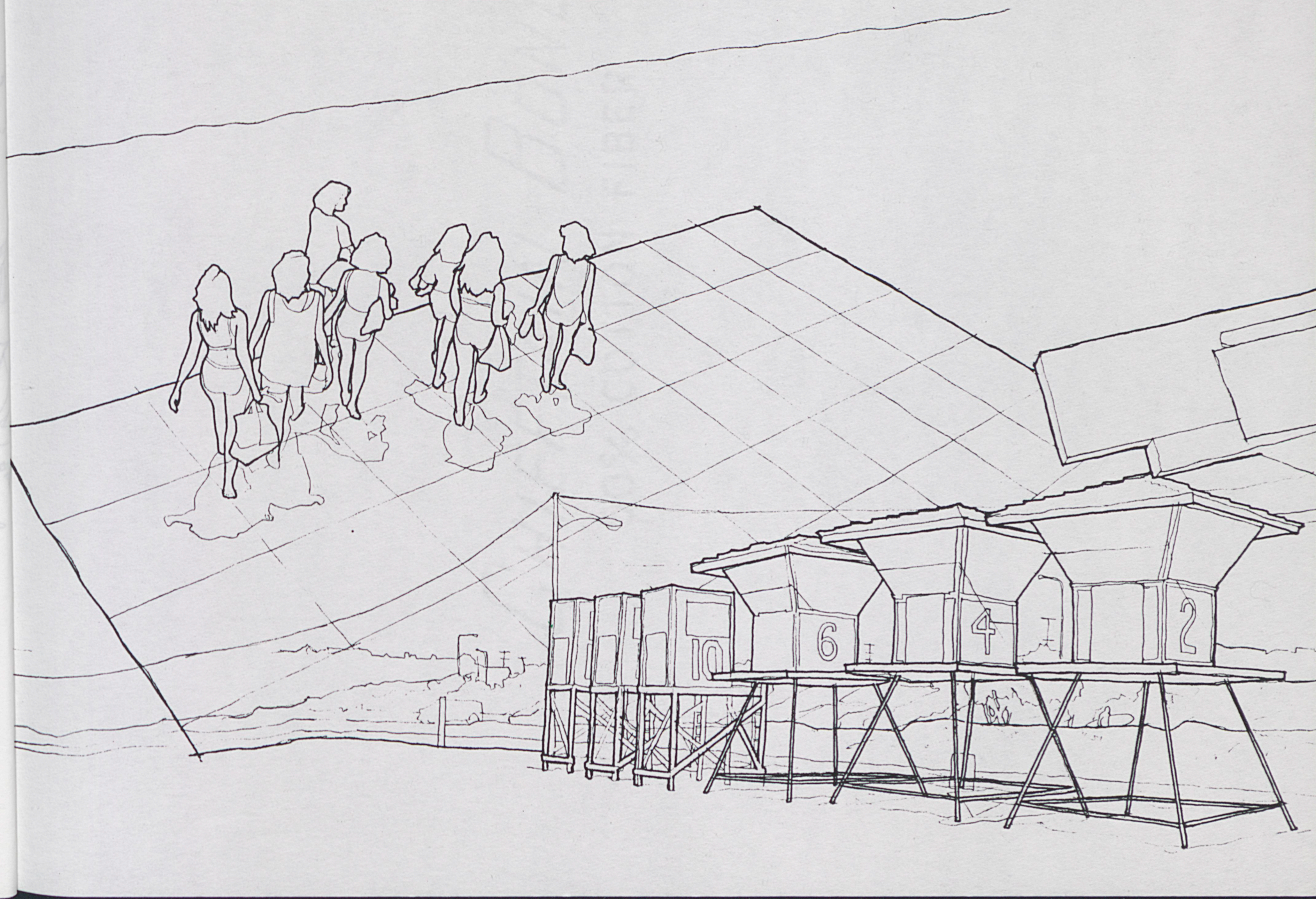
# EXISTING PIER



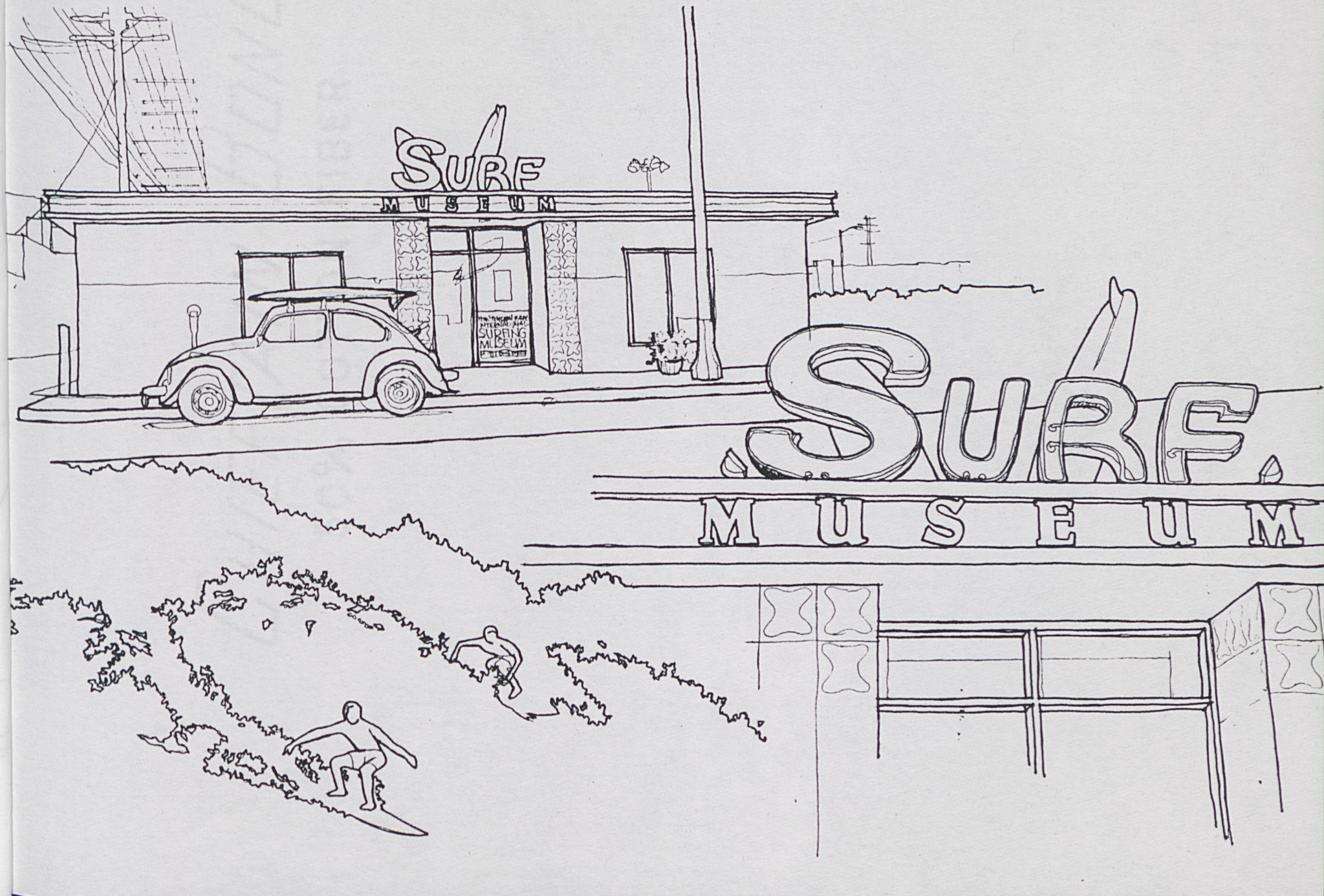
# MAIN STREET



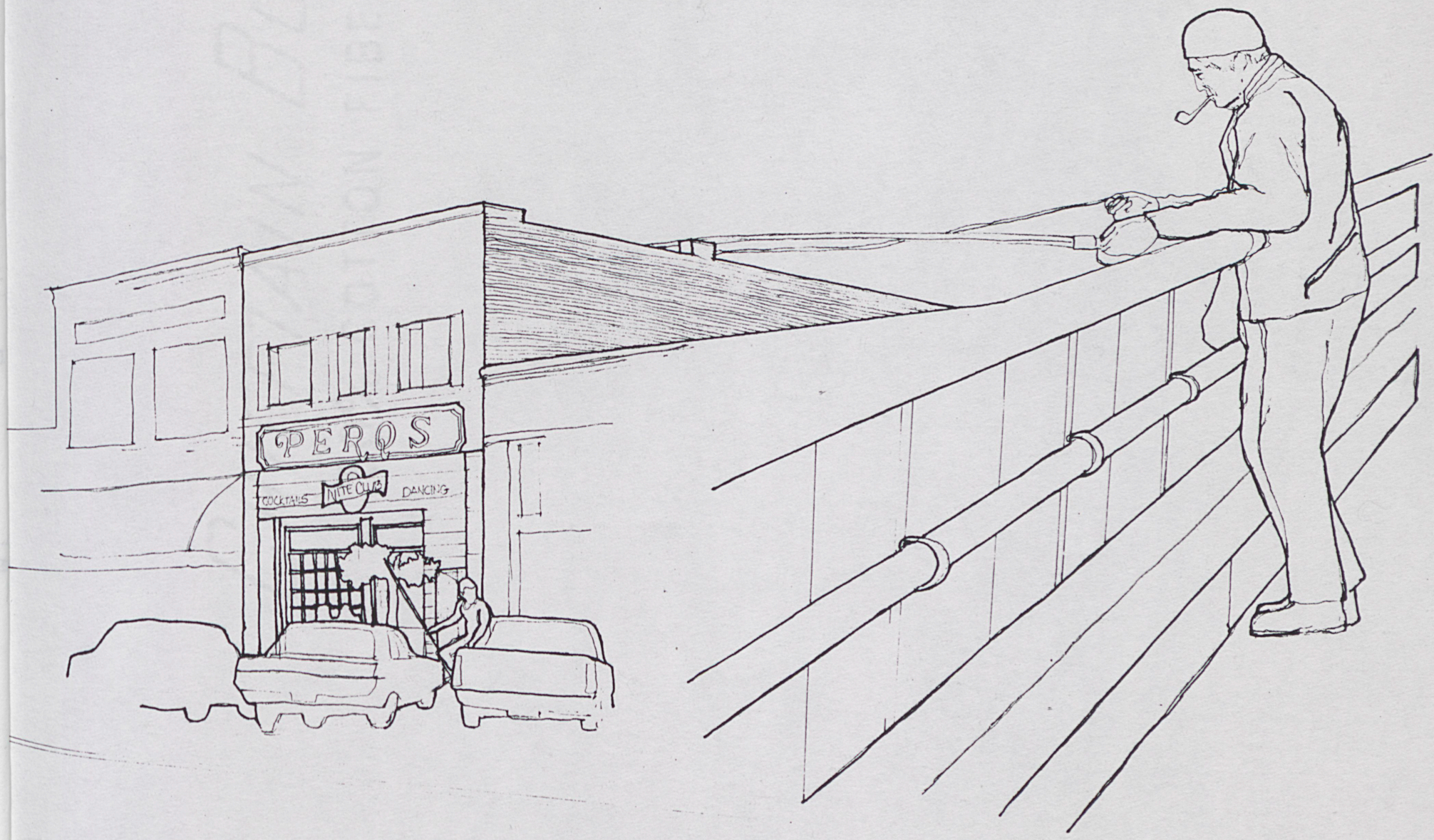
# THE BEACH

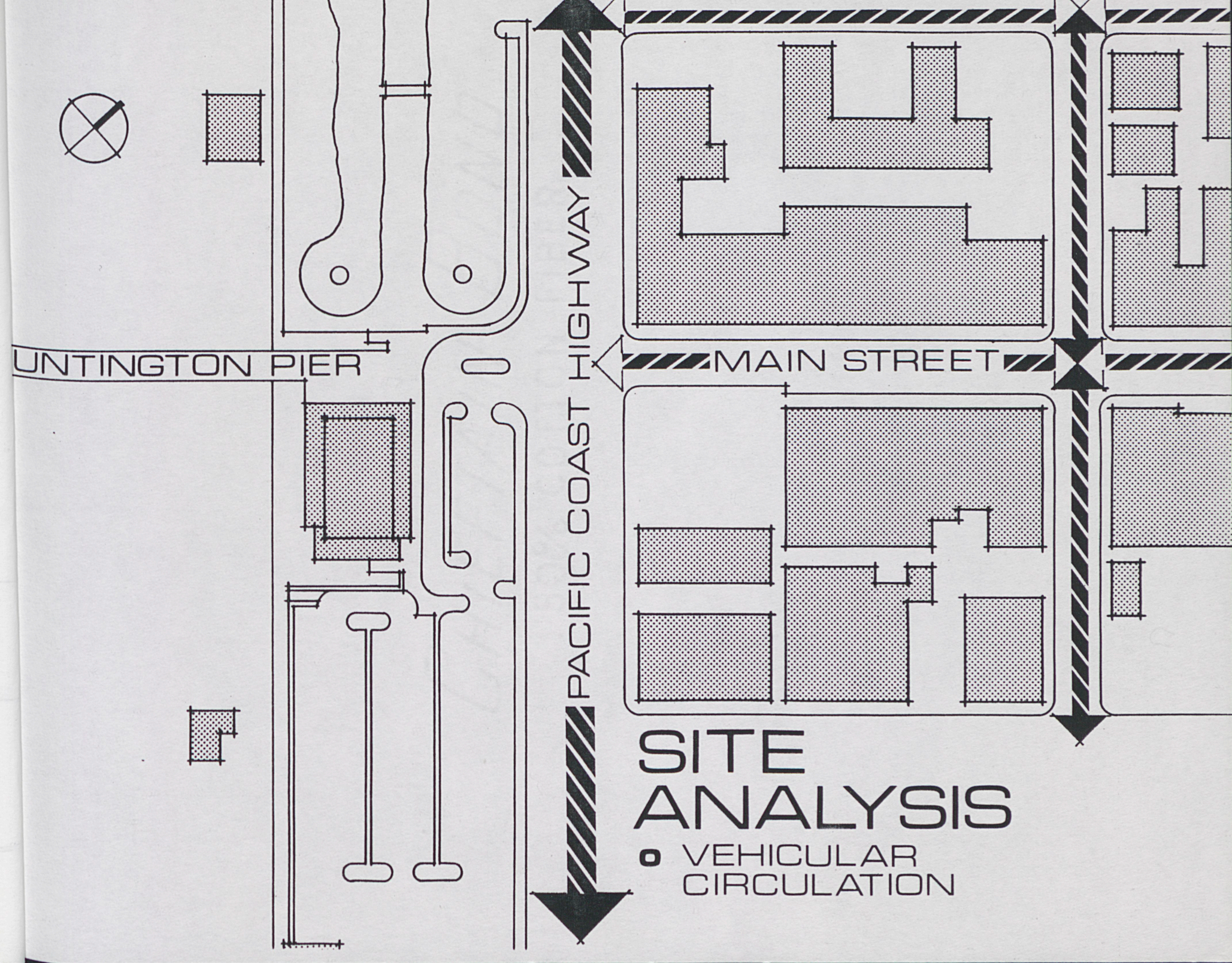


# THE SURFER



# THE FISHERMAN



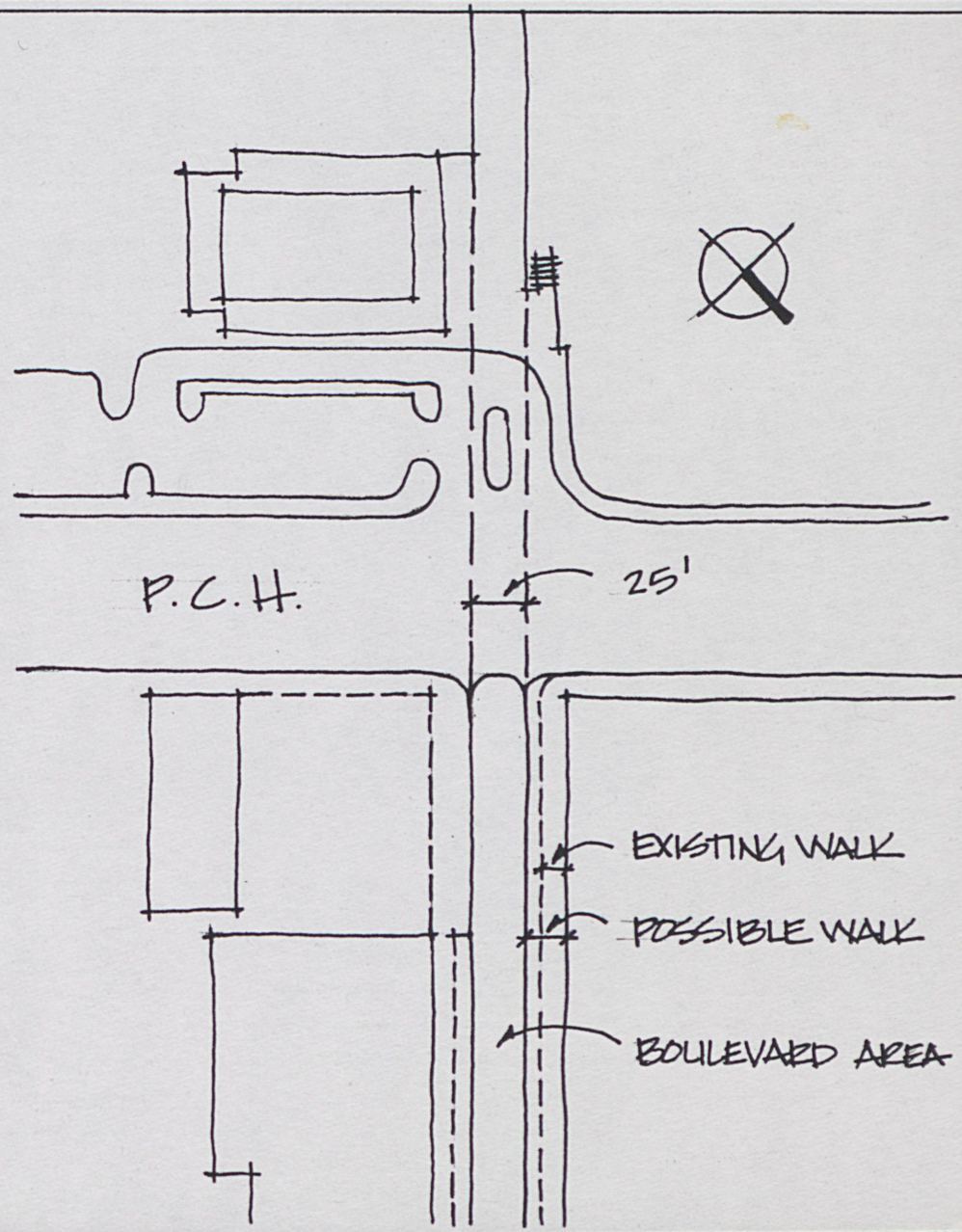

UNTINGTON PIER
PACIFIC COAST HIGHWAY
MAIN STREET
SITE
ANALYSIS
VEHICULAR
CIRCULATION

# DESIGN RESPONSE

1. VEHICULAR SITE CIRCULATION IS SUCCESSFUL AS IS. NO FURTHER INTERRUPTION OF P.C.H. THAN THE ESTABLISHED CROSS WALKS WOULD NOT BE PLAUSIBLE.

2. POSSIBILITY OF RESTRICTING TRAFFIC FROM MAIN STREET TO MAKE IT A PURELY PEDESTRIAN WAY WITH A BOULEVARD IN THE CENTER OF THE SAME WIDTH AS THE PIER.

# VIGNETTES



# SITE ANALYSIS

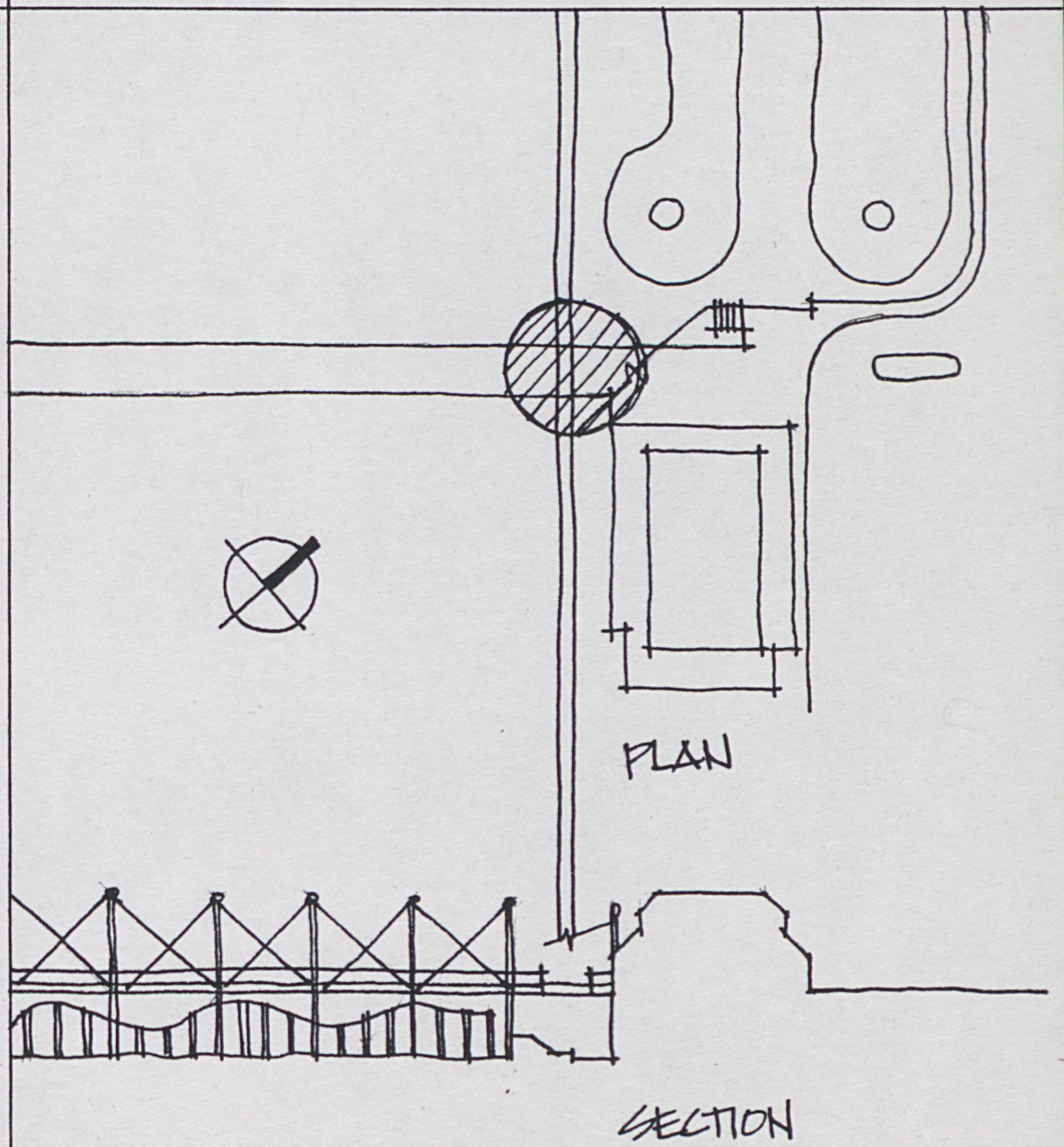
- BICYCLE CIRCULATION

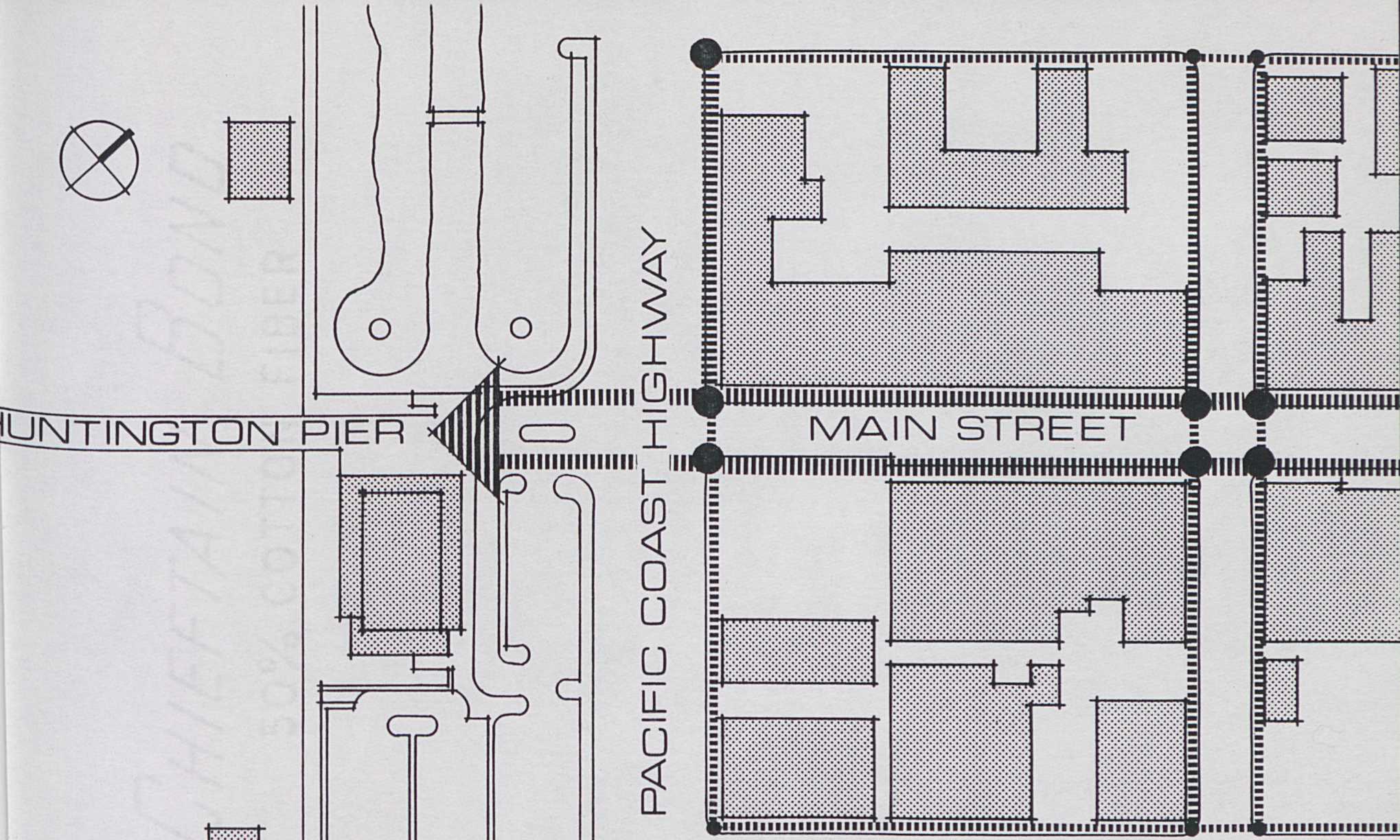
# DESIGN RESPONSE

1. NECESSARY TO RESOLVE THE INTERSECTION BENEATH THE LAND BASED BEGINNING OF PIER WHERE LONG DISTANCE BIKERS CONVERGE WITH PEDESTRIANS, SKATEBOARDERS, AND TRICK-BIKERS.

2. POSSIBLE USE OF LEVEL CHANGES TO RE-ROUTE TOURING BIKERS TO BYPASS THE STATIC TRAFFIC.

# VIGNETTES






# SITE ANALYSIS

- PEDESTRIAN CIRCULATION

# DESIGN RESPONSE

1. ALLOW PEDESTRIAN CIRCULATION TO CONTINUE ALONG SAME ROUTE; THE EXCEPTION BEING MAIN STREET IF REDUCED TO PEDESTRIAN TRAFFIC ONLY, IN WHICH CASE THE PEDESTRIAN ROUTE WOULD BE EXPANDED. (SEE VEHICULAR CIRCULATION RESPONSE AND VIGNETTE).

# SITE ANALYSIS

o PARKING

EXISTING PARKING

# DESIGN RESPONSE

1. BEACH LOTS AND INLAND PARKING PROVIDE ADEQUATE PARKING FOR SITE AND WILL REMAIN AS THEY ARE. AN EXCEPTION TO THIS WOULD BE THE REMOVAL OF DIAGONAL PARKING ALONG MAIN STREET IF IT WERE TO BE CLOSED TO AUTO-MOBILES.

# SITE ANALYSIS

o VEGETATION

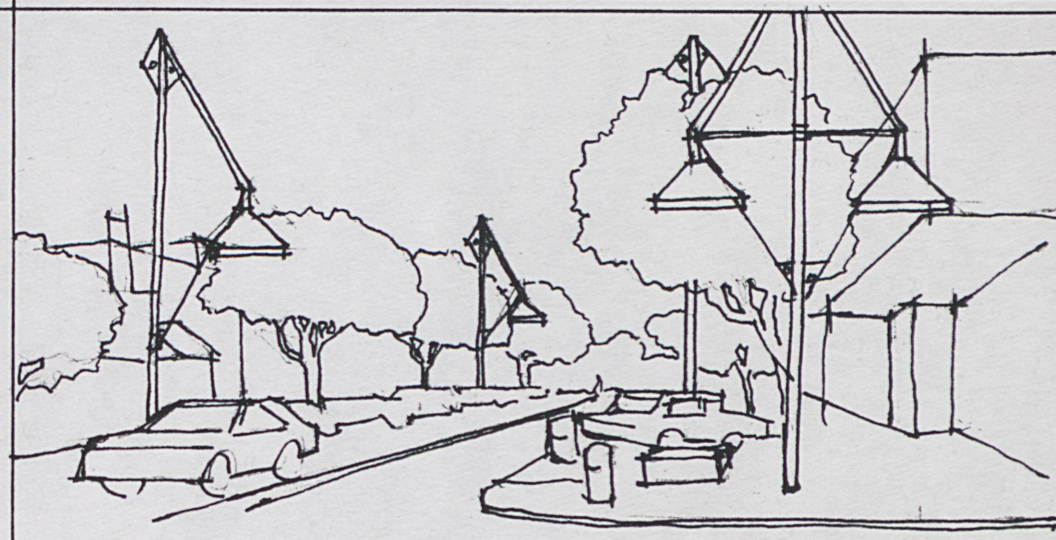
# DESIGN RESPONSE

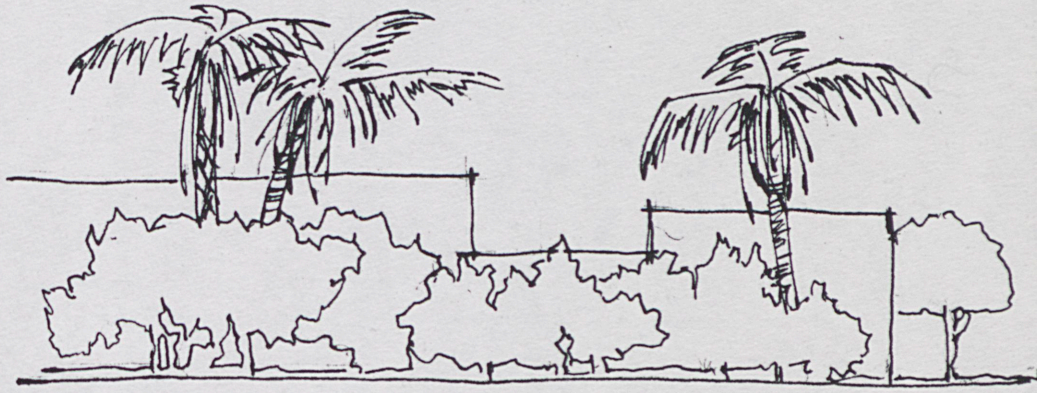
1. LEAVE, UNALTERED, THE EXISTING VEGETATION EXCEPT THAT WHICH IS IMMEDIATELY AFFECTED BY THE PIER/MAIN STREET INTERSECTION.

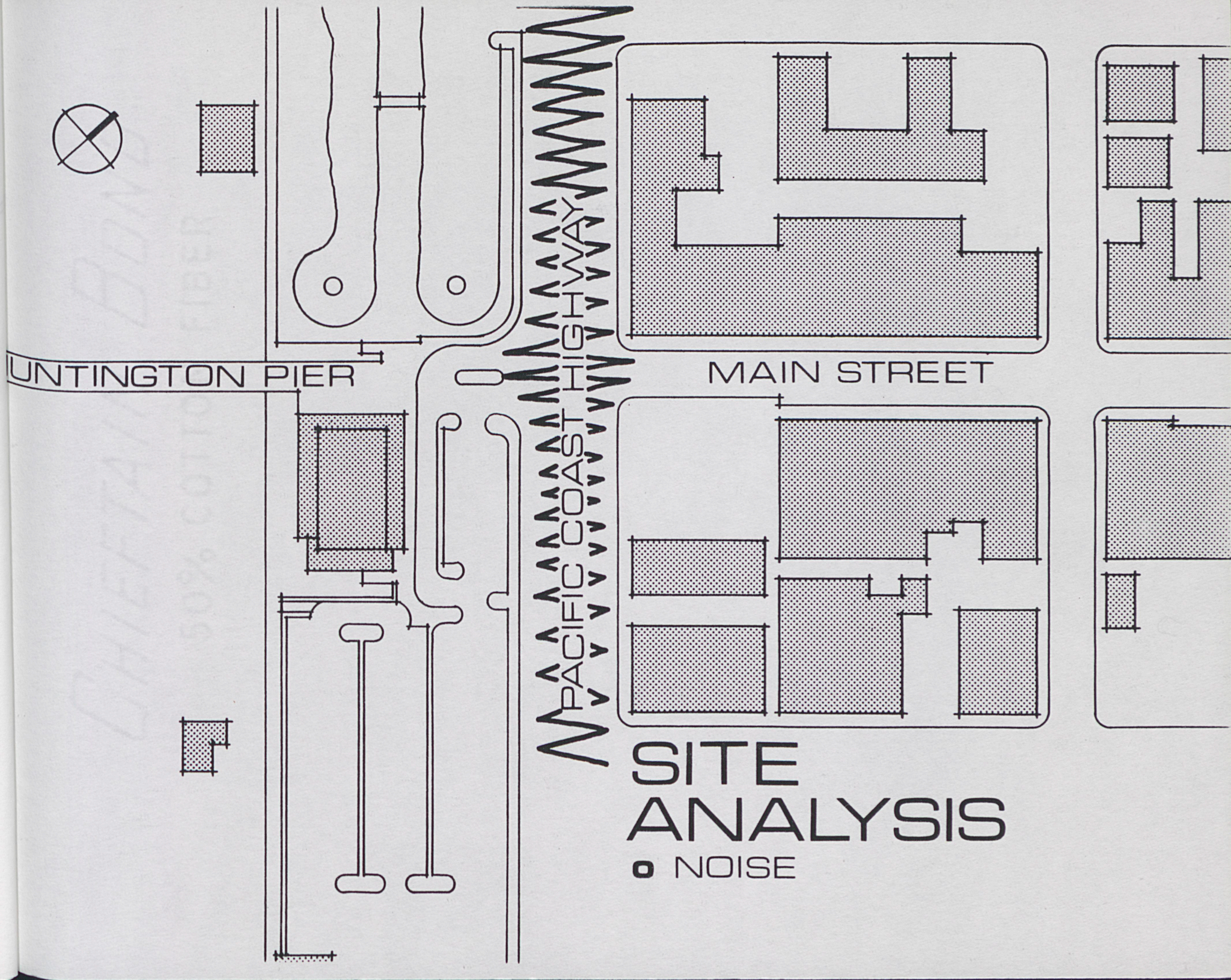
2. PLAY THE CONTRAST BETWEEN THE INFORMAL NATURE OF VEGETATION AND THE RIDGID GEOMETRY OF STRUCTURAL MEMBERS.

3. USE OF VEGETATION FOR VISUAL SCREENING OF P.C.H. TRAFFIC.

# VIGNETTES





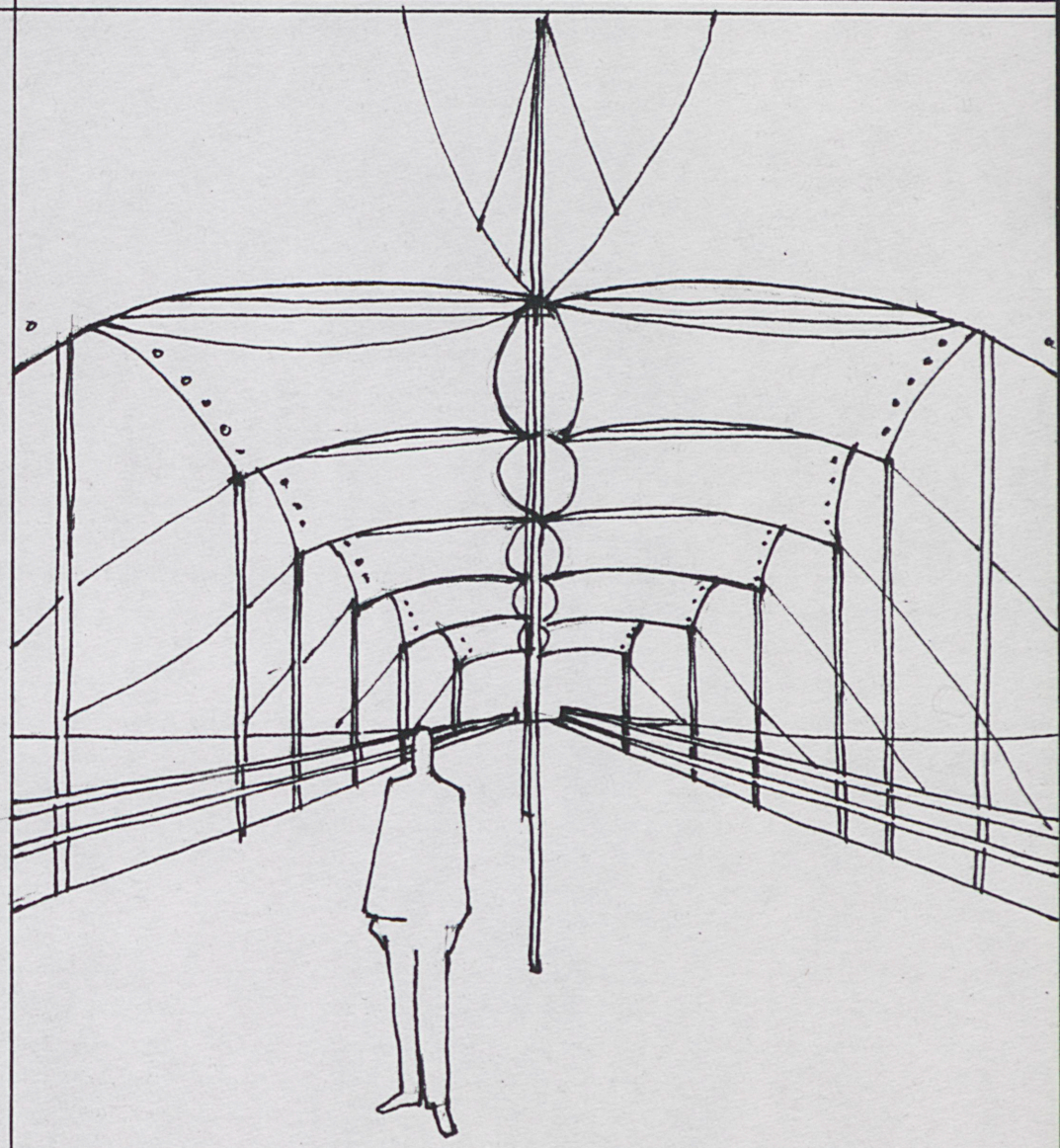

UNTINGTON PIER
PACIFIC COAST HIGHWAY
MAIN STREET
SITE
ANALYSIS
NOISE

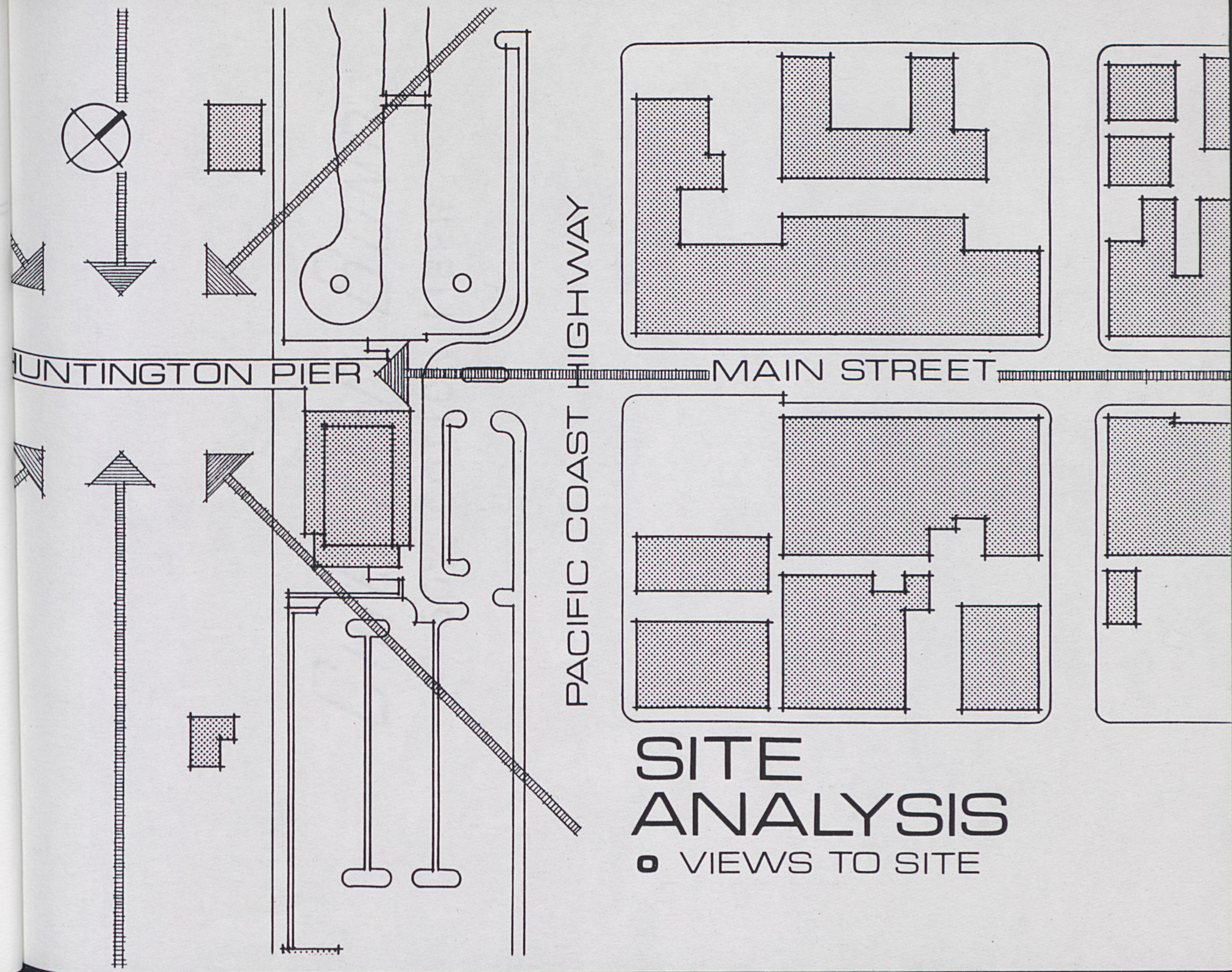
# DESIGN RESPONSE

1. MAN-MADE TRAFFIC NOISE ALONG P.C.H. IS AN ACCEPTED AND RELATIVELY UNOBTRUSIVE PART OF THE SITE. THE NOISE IS PARTIALLY MASKED BY THE NATURAL SOUND OF WIND AND OCEAN.

2. POSSIBILITY OF FURTHER MASKING TRAFFIC NOISE THROUGH MATERIAL USAGE IN PIER STRUCTURE, I.E. - CANVAS AND RIGGING IN AN OVERHEAD PLANE.

# VIGNETTES






# SITE ANALYSIS

- VIEWS TO SITE

# DESIGN RESPONSE

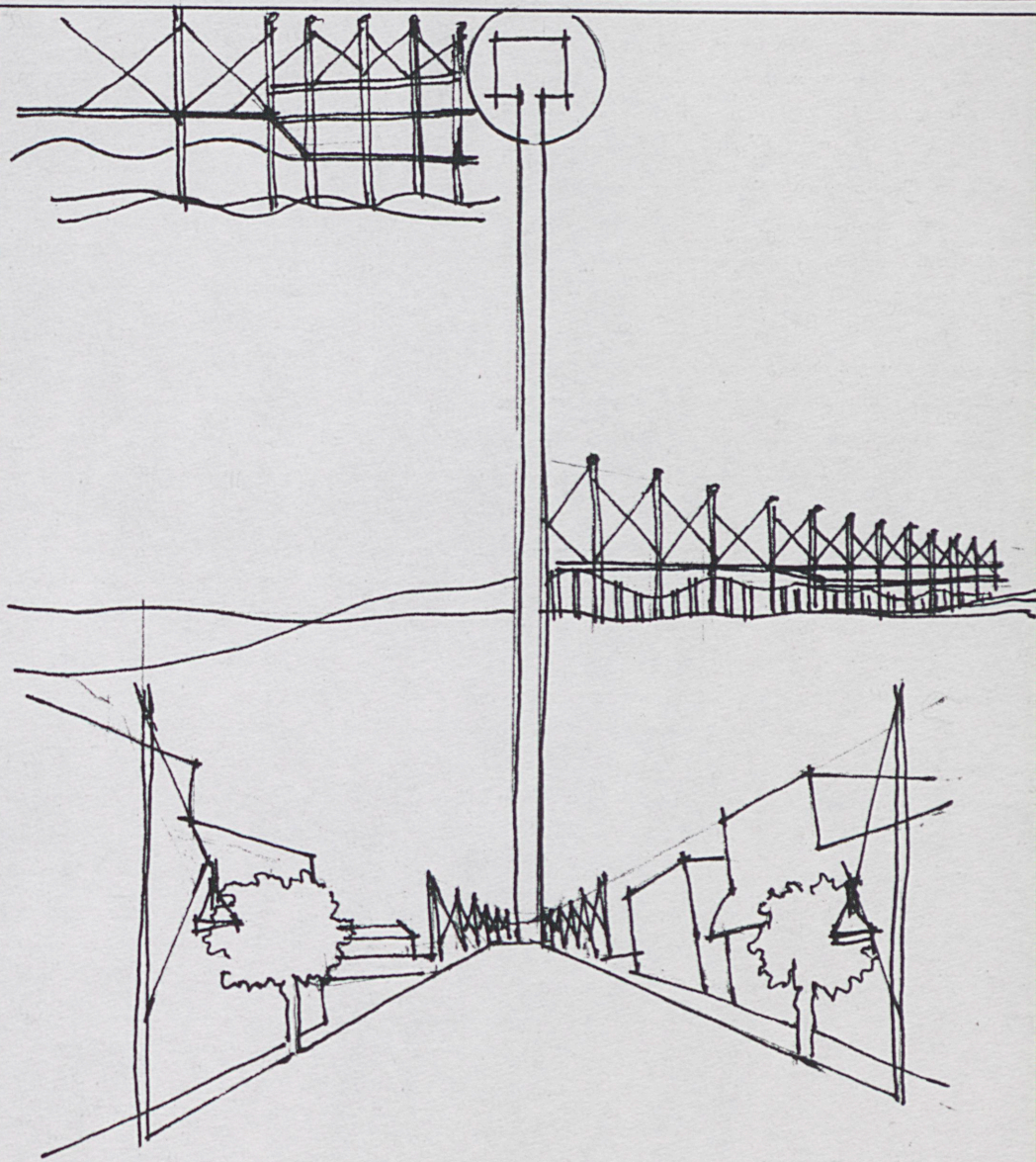
1. VIEWS TO SITE ARE DISTINCTLY DIFFERENT, BUT EQUALLY IMPORTANT, FROM A VARIETY OF VANTAGE POINTS.

MAIN STREET: VIEW SHOULD HAVE VISUAL CONTINUATION FROM MAIN STREET TO PIER TO CREATE A LONG, DRAMATIC PERSPECTIVE.

P.C.H.: SEEN, FOR THE MOST PART, OBLIQUELY AND AT A DISTANCE TOO GREAT TO VIEW DETAILS. PIER IMAGE SHOULD BE INTERESTING AS A MONOLITHIC WHOLE WITH A LANDMARK OR ICONOGRAPHIC QUALITY.

BEACH: SIMILIAR TO P.C.H. VIEW EXCEPT FOR DIFFERENCE IN VIEWER'S SPEED (PEDESTRIAN / CYCLING AS OPPOSED TO VEHICULAR). THE ICONOGRAPHIC QUALITY MUST WORK UP CLOSE AS WELL AS FAR AWAY.

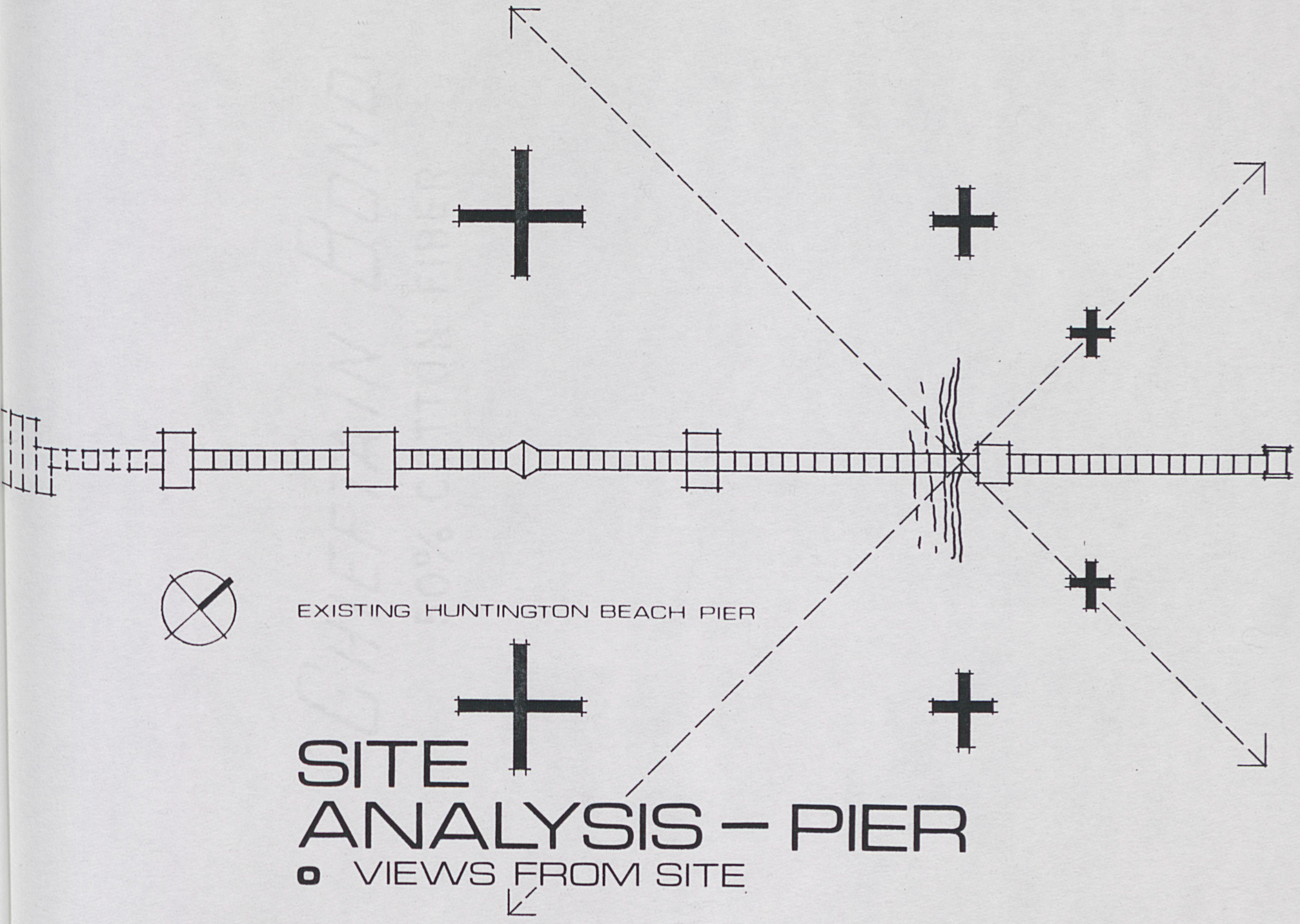
# VIGNETTES



# DESIGN RESPONSE

# VIGNETTES

WATER: MUST ALSO POSSESS A LAND-MARK QUALITY WHEN VIEWED AT A DISTANCE. POSSIBILITY, TOO, OF INCORPORATING A SAFETY OR ORIENTATION QUALITY FOR BOATING IN POOR WEATHER. THIS COULD BE ACHIEVED THROUGH BOTH THE PIER FORM ITSELF AS WELL AS THROUGH SAFETY LIGHTING.



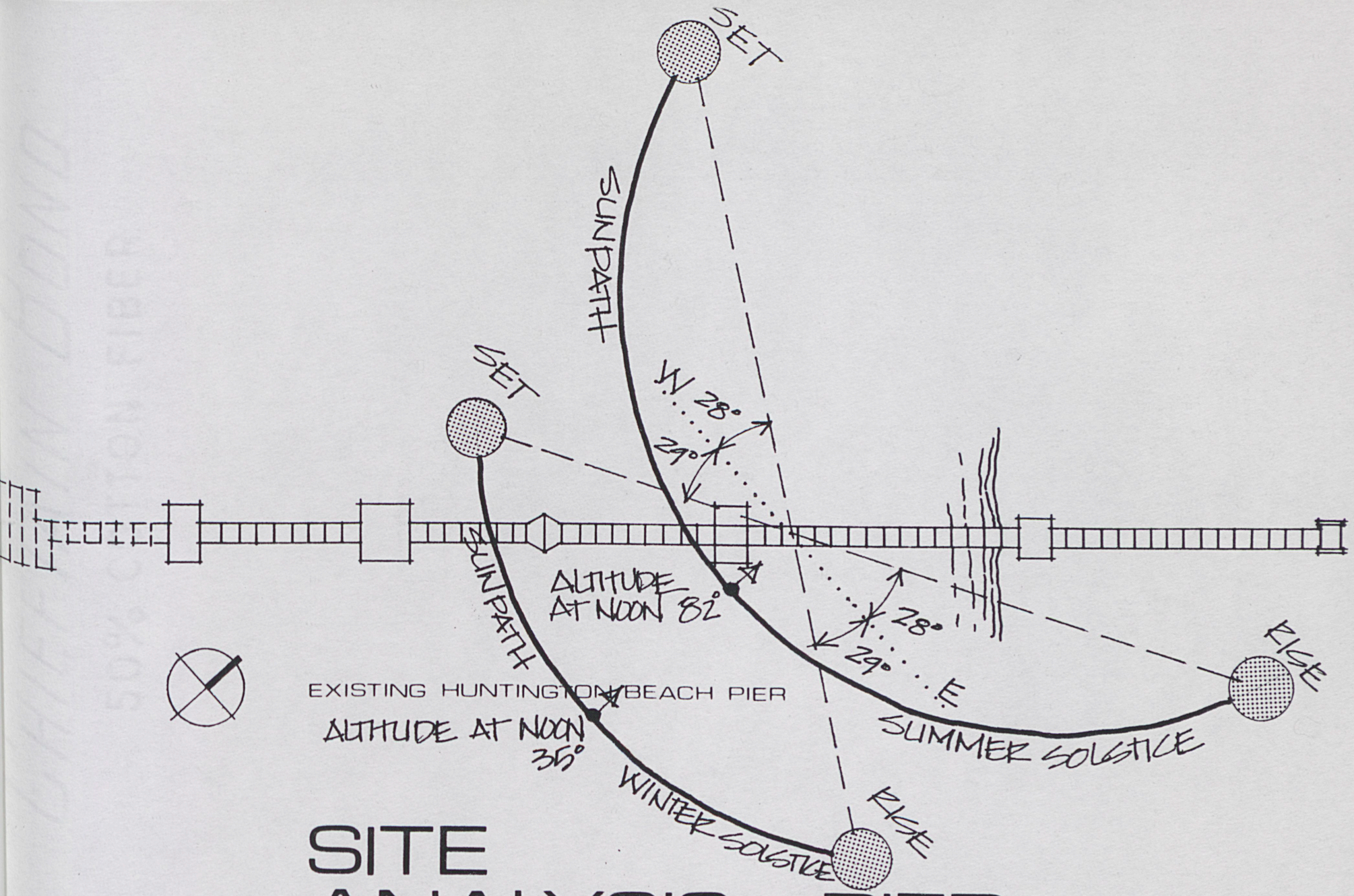

# SITE ANALYSIS – PIER

- VIEWS FROM SITE

# DESIGN RESPONSE

1. ALTHOUGH NO VIEW FROM THE PIER IS UNDESIRABLE, THE MOST SOUGHT AFTER VIEWS ARE THE OPEN SEASCAPES AS OPPOSED TO VIEWS BACK TO SHORE.

2. PROVIDE OBSERVATION POINTS ALONG PIER TO MAXIMIZE ACCESS TO VIEWS.



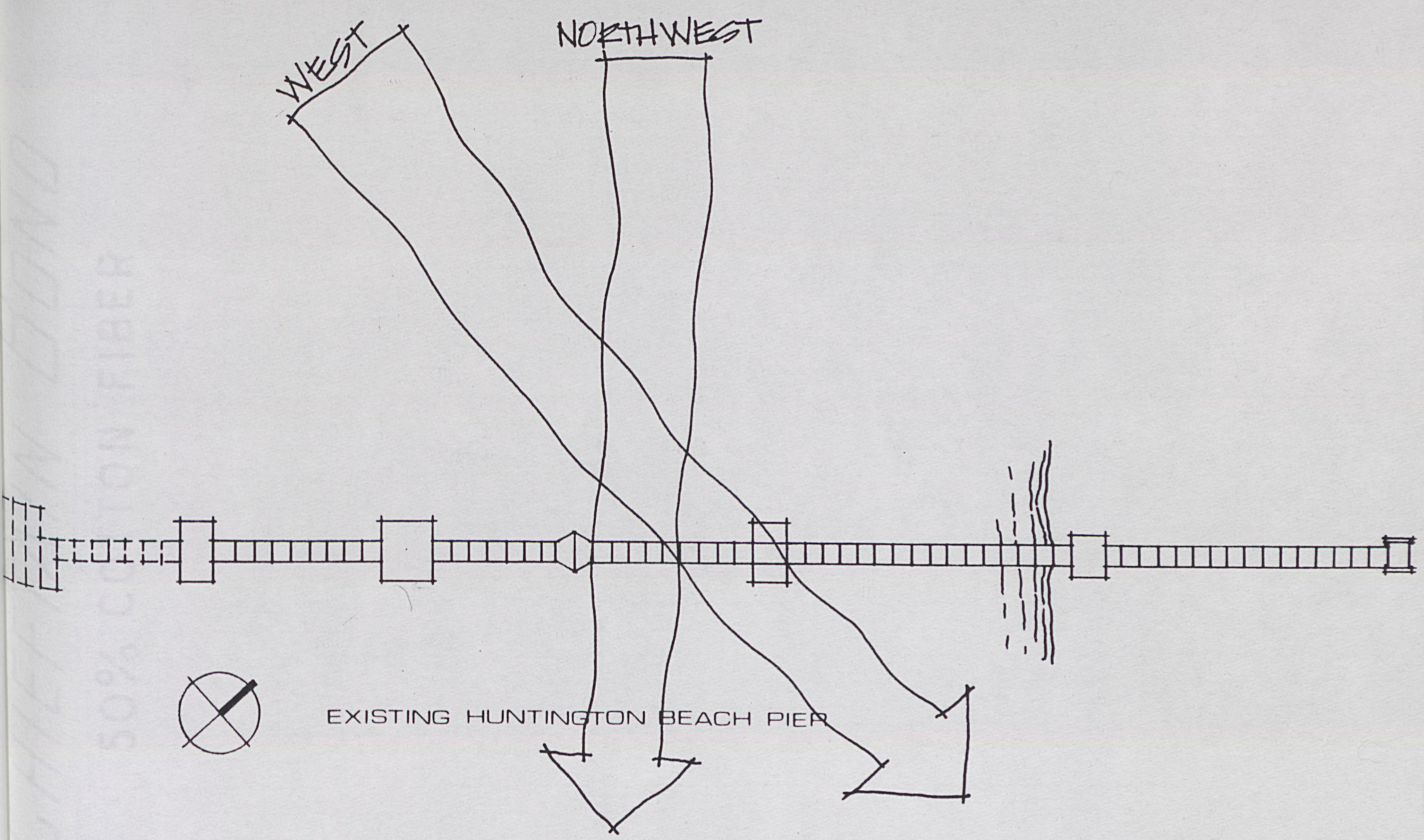

# SITE ANALYSIS – PIER

- SUNPATH

# DESIGN RESPONSE

1. HIGH YEAR ROUND SUN EXPOSURE TO SITE VALIDATES USE OF SHADING DEVICES, BOTH PERMANENT AND MOBILE, ON PIER BUILDINGS AND OVER SEATING AREAS.

2. PROVIDE PIER USERS WITH SUN EXPOSURE OPTIONS USING THE ABOVE METHODS.



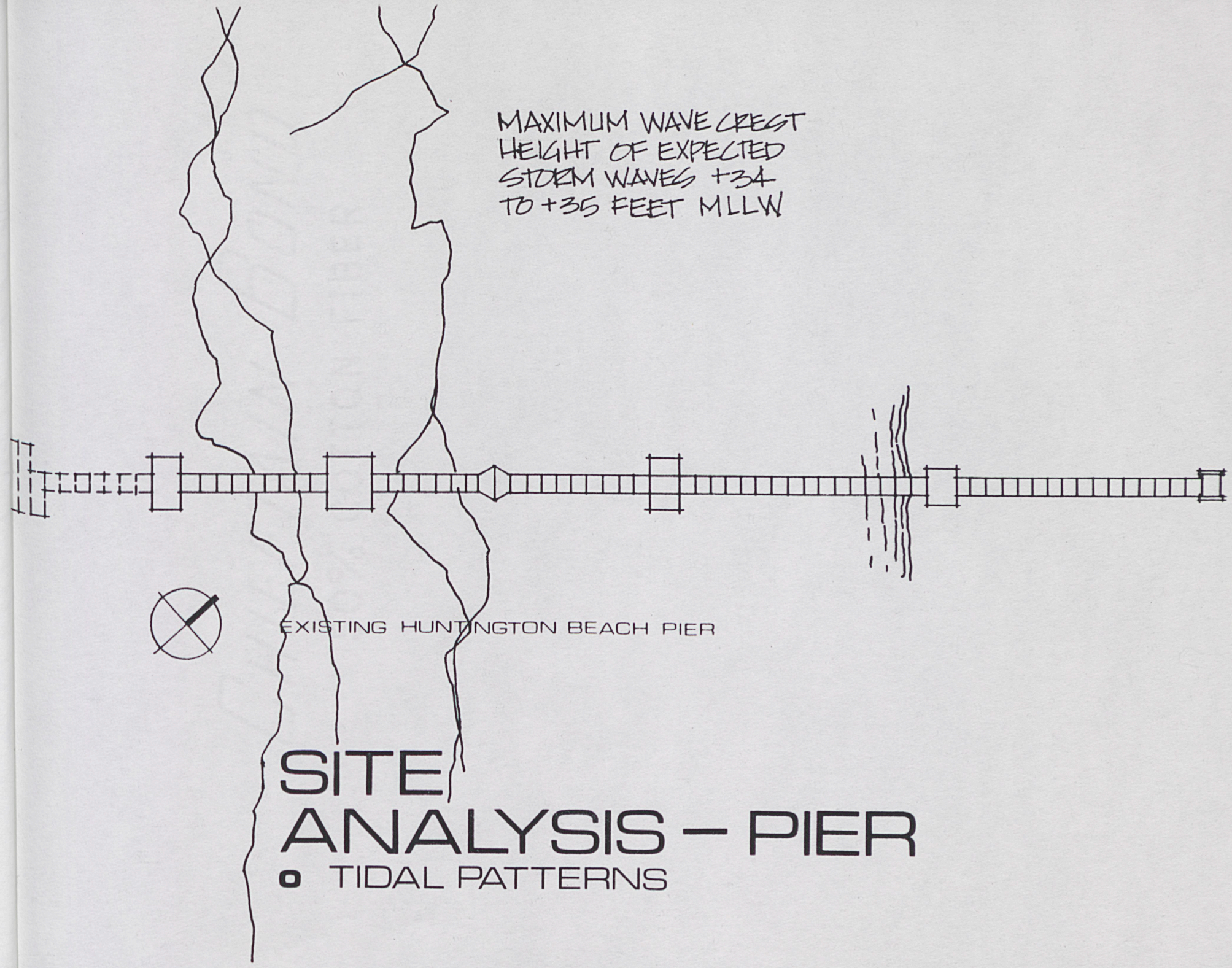

# SITE ANALYSIS – PIER

- WIND

# DESIGN RESPONSE

1. THE PREVAILING WIND DIRECTIONS ARE FROM THE WEST AND NORTH-WEST WITH WIND SPEEDS GENERALLY 4 TO 10 KNOTS.

2. OCEAN BREEZES GENERALLY CONSIDERED TO BE DESIRABLE FOR THEIR COOLING EFFECT. MAXIMIZE THIS POTENTIAL IN OUTDOOR SEATING ARRANGEMENTS AND IN BUILDING COOLING SYSTEMS.




# SITE ANALYSIS – PIER

- TIDAL PATTERNS

# DESIGN RESPONSE

1. TIDES ALONG THE CALIFORNIA COAST ARE CHARACTERIZED AS MIXED SEMI-DIURNAL, AND CONSIST OF TWO UNEQUAL HIGH TIDES AND LOW TIDES EACH DAY. THE CLOSEST TIDE REFERENCE STATION IS AT LOS ANGELES HARBOR. THERE IS NO DIFFERENCE BETWEEN PREDICTED TIDE HEIGHTS AT LOS ANGELES AND THE HUNTINGTON BEACH MUNICIPAL PIER, HOWEVER THERE IS AN APPROXIMATE 30 MINUTE TIME LAG.

2. THE DECK ELEVATION OF THE NEW PIER SHOULD BE RAISED ABOUT 10 FEET HIGHER THAN THE EXISTING PIER ELEVATION. THIS WOULD PUT THE NEW PIERHEAD ELEVATION AT +37 FT. MLLW SO AS TO BE ABOVE THE MAXIMUM CREST HEIGHT OF EXPECTED STORM WAVES (+34 TO 35 FT. MLLW).

# PROGRAM

FINAL FACILITY TO INCLUDE:°

1. STRUCTURAL STEEL PIER, 25 FEET WIDE (TYPICAL) AND 1,822 FEET LONG WITH MAXIMUM DECK ELEVATION VARYING FROM 34 FEET TO 37 FEET MLLW, INTEGRATED WITH THE FOLLOWING:
2. PIERHEAD RESTAURANT
3. PUBLIC RESTROOMS
4. LIFE GUARD TOWER
5. BAIT SHED
6. FISHING DECKS WITH FISH CLEANING STATIONS
7. ELECTRICAL SHED
8. MULTIPLE SEATING AREAS LOCATED INTERMITTENTLY ALONG PIER
9. DIVIDED PUB & SNACK BAR
10. ACCESS RAMP FROM BEACH TO PIER
11. MULTI-LEVEL SEATING FOR SPECTATORS OF AQUATIC SPORTS
12. DESIGNATED SKATEBOARD / TRICK BIKE AREA
13. HANDRAILS, BENCHES, LIGHTING & ALL UTILITIES

° THE PROGRAM GIVEN IS SPECULATORY AND MAY VARY TO INCLUDE ADDITIONAL EVENTS IN THE FINAL DESIGN.

# PRECEDENTS

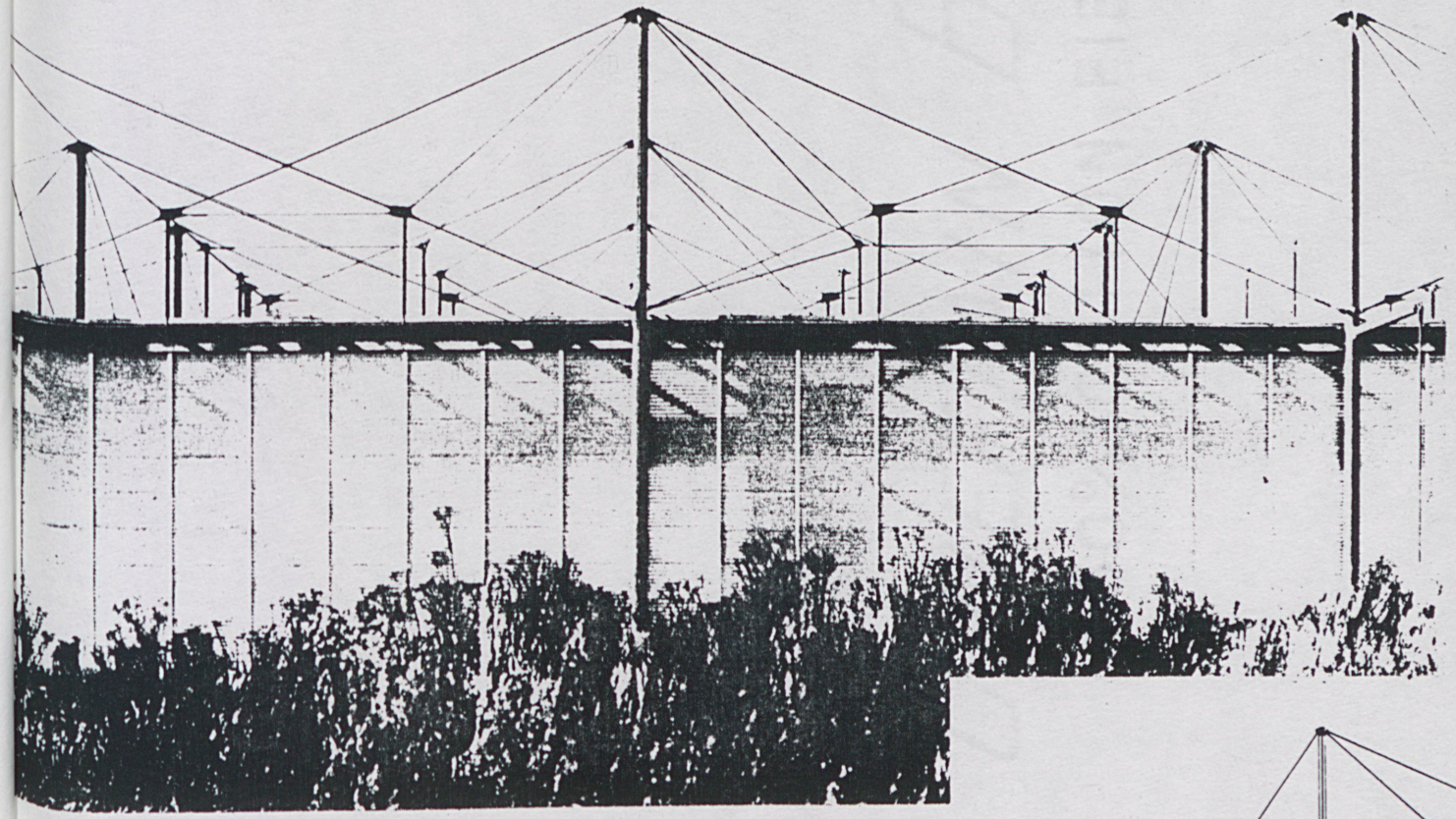
THE ARCHITECTURAL PRECEDENTS THAT FOLLOW WERE NOT CHOSEN FOR THEIR SIMILARITY IN PROGRAMMATIC REQUIREMENTS OR SITE CONDITIONS TO A PIER STRUCTURE. THEY WERE, INSTEAD, CHOSEN ON THE BASIS OF THE STRUCTURAL SYSTEMS USED. IMPORTANT IN EACH EXAMPLE IS THE OVERALL INTEGRATION OF STRUCTURE WITH BUILDING, ENCLOSURE, AND SUPPORT SYSTEMS. IMPORTANT, TOO, IS THE WAY EACH DEALS WITH STRUCTURE, CONNECTIONS, AND MATERIALS AT A HUMANISTIC LEVEL.

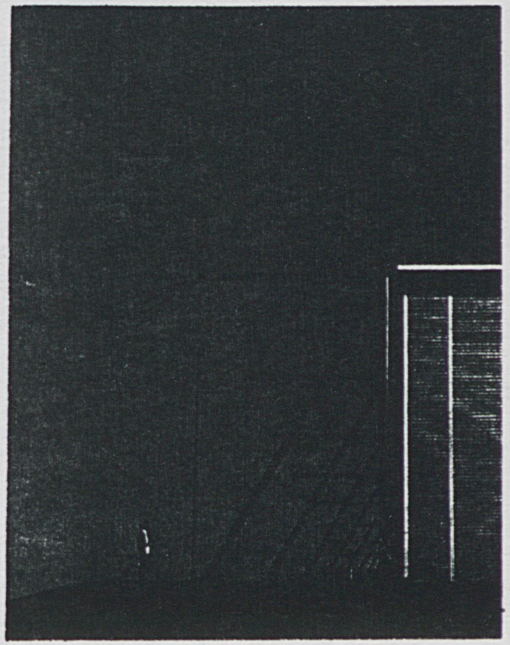
# PRECEDENTS

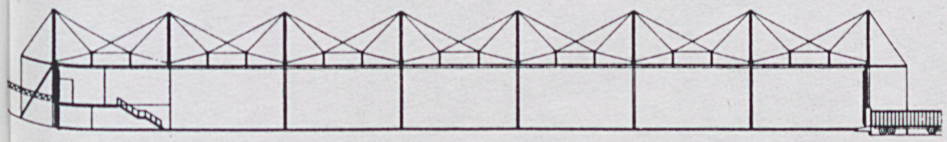
RICHARD ROGERS PARTNERSHIP

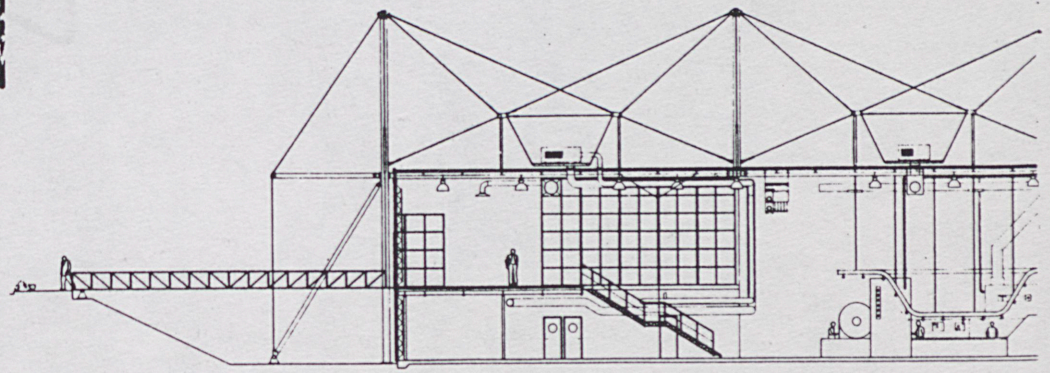
FLEETGUARD MANUFACTURING AND DISTRIBUTION CENTER; QUIMPER, FRANCE

SEE BIBLIOGRAPHY NO. 2, P. 22









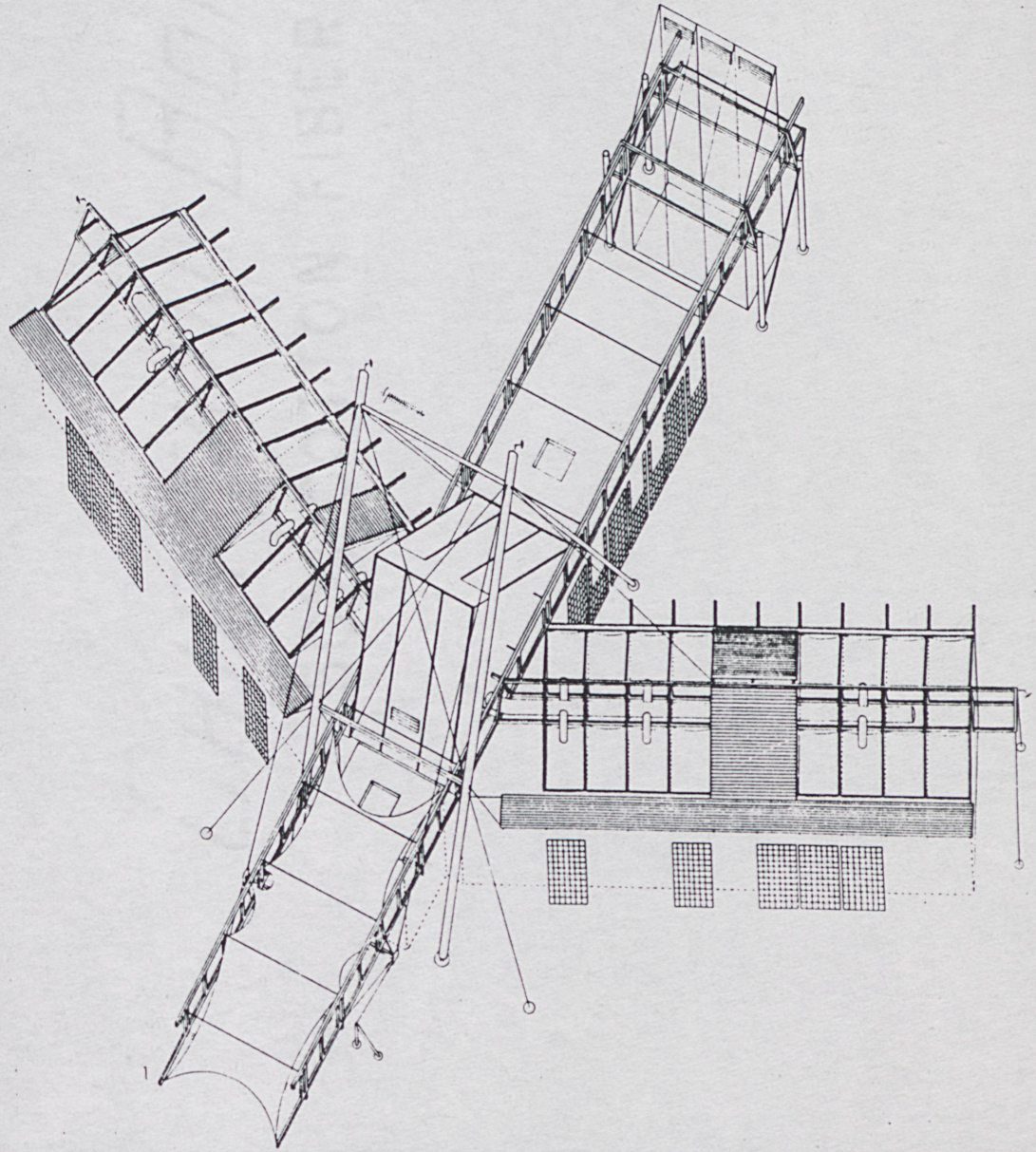
# PRECEDENTS

IAN RITCHIE

EAGLE ROCK HOUSE; CROWBOROUGH

SEE BIBLIOGRAPHY NO. 2, P. 128



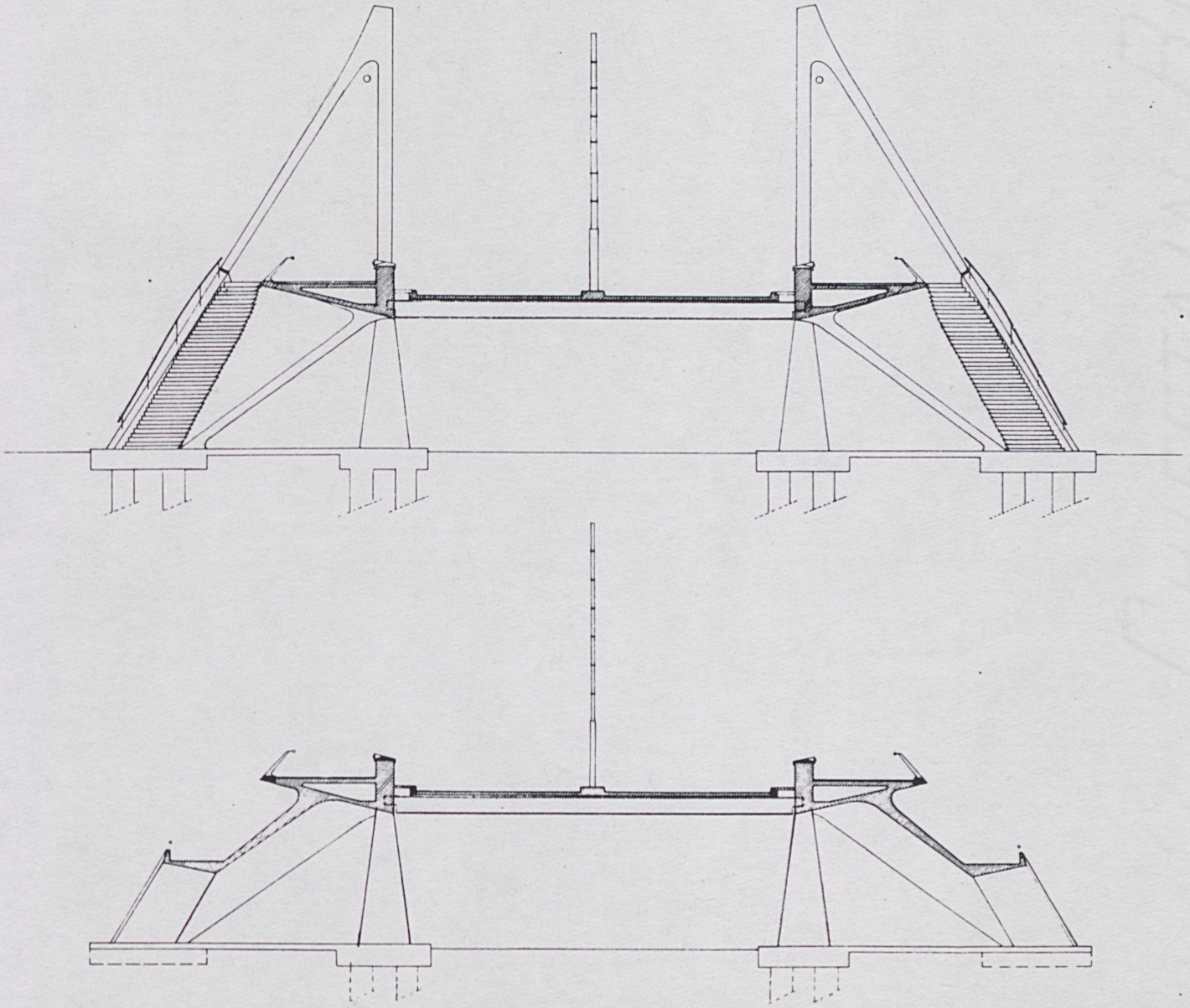


# PRECEDENTS

SANTIAGO CALATRAVA

ROAD BRIDGE LINKING FELIPE II AND BACH DE RODA IN BARCELONA

SEE BIBLIOGRAPHY NO. 3, P. 87

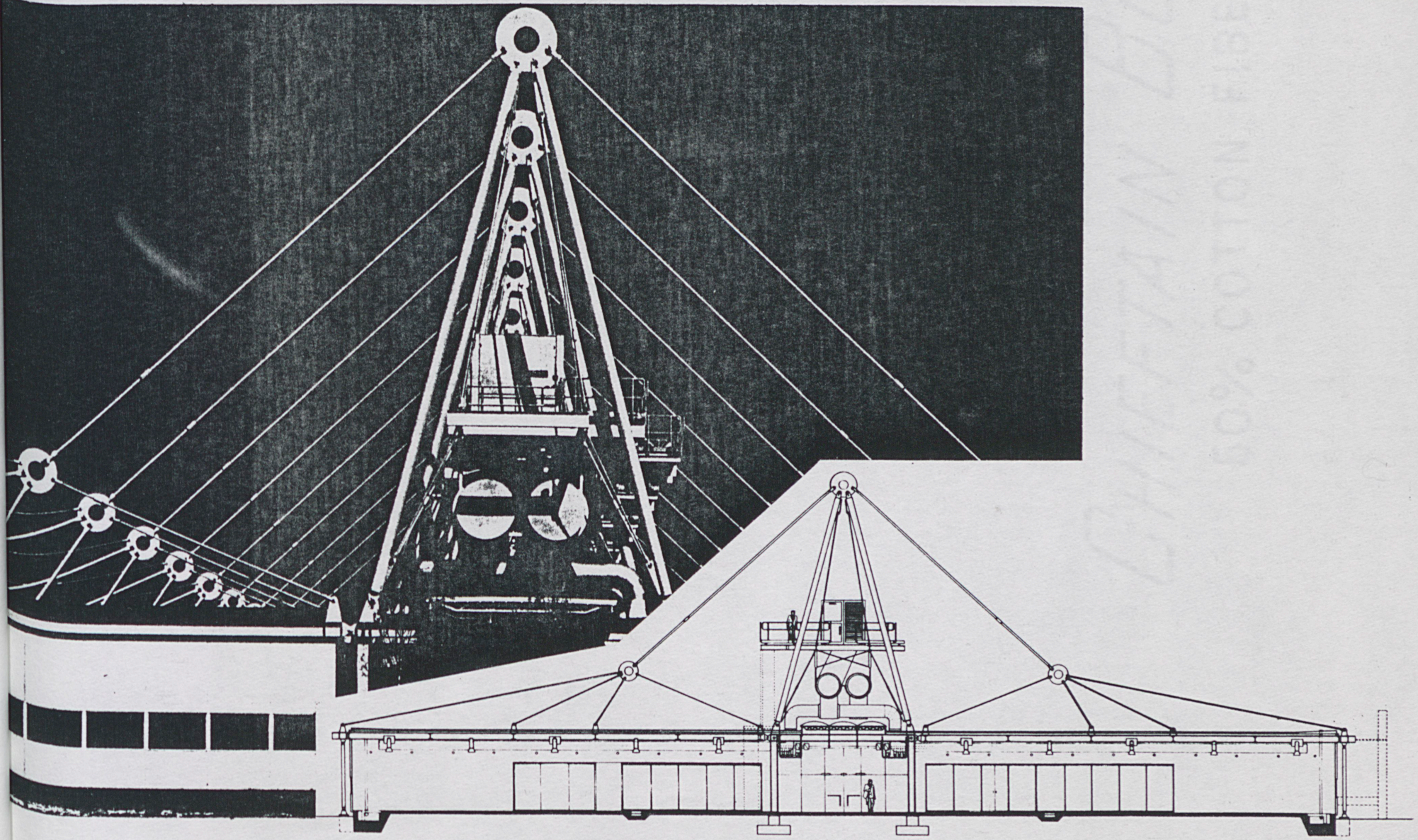


# PRECEDENTS

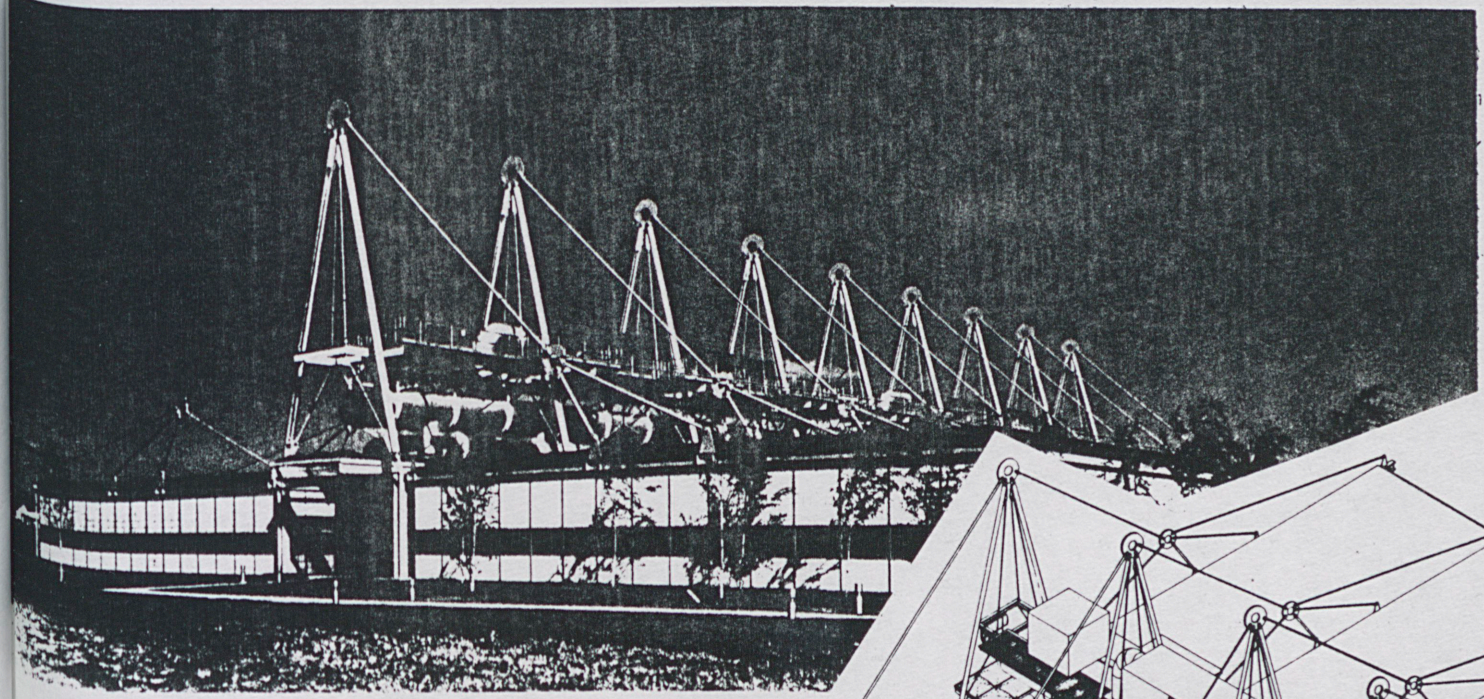
RICHARD ROGERS PARTNERSHIP

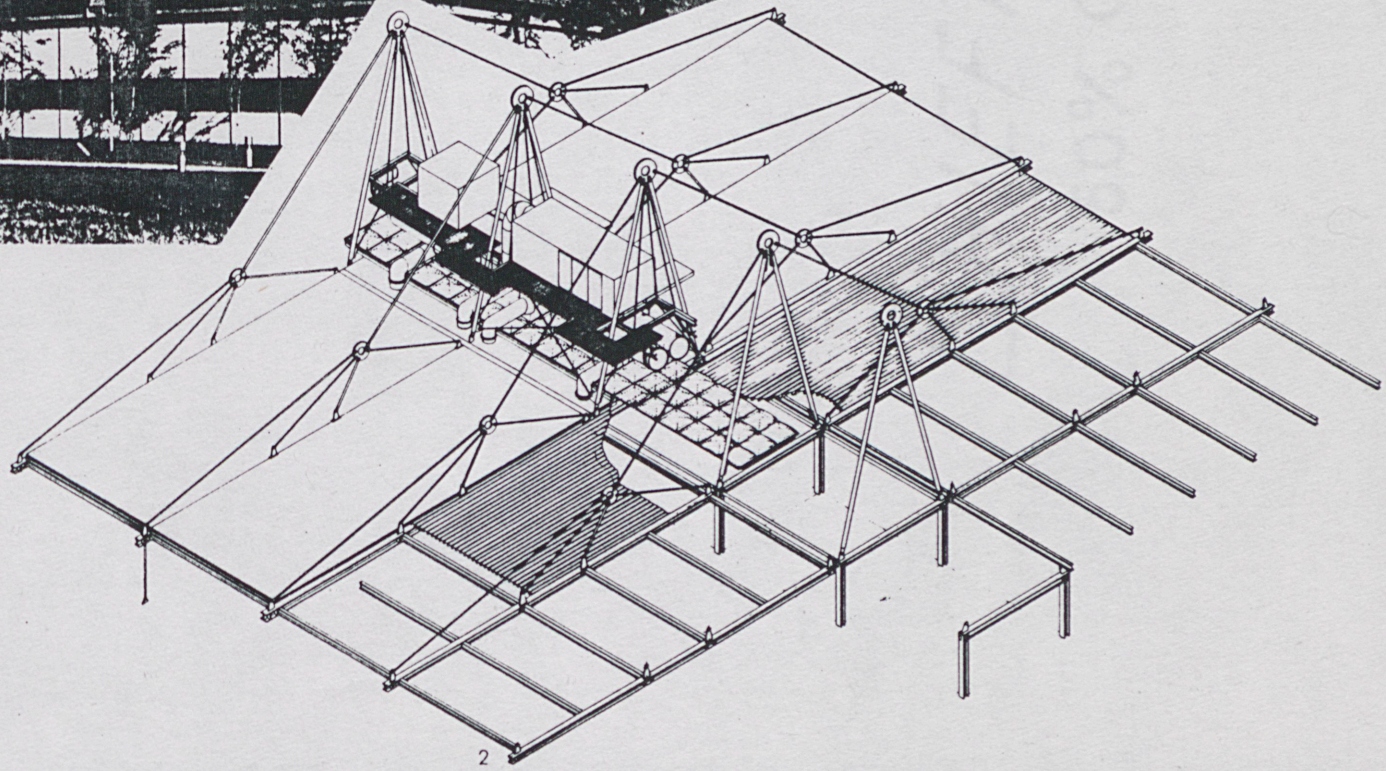
LABORATORIES AND CORPORATE FACILITY FOR PA TECHNOLOGY; PRINCETON, NEW JERSEY

SEE BIBLIOGRAPHY NO. 2, P. 32



# PRECEDENTS



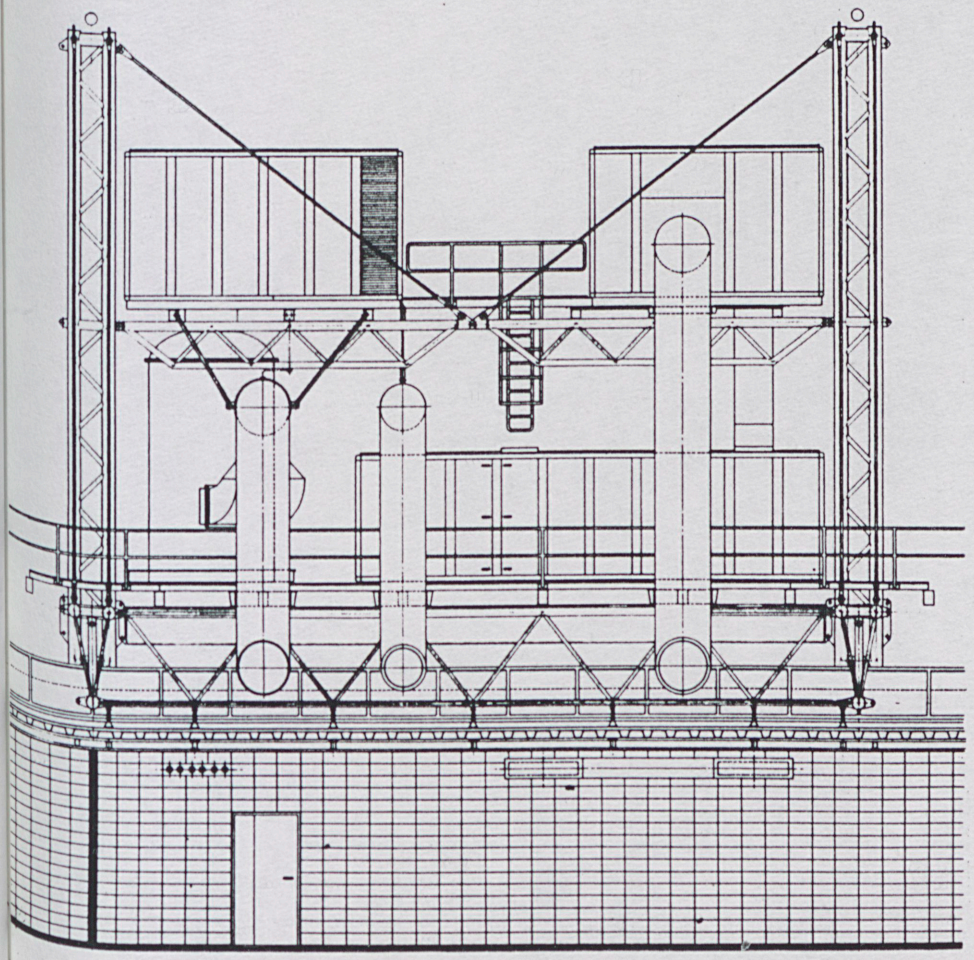


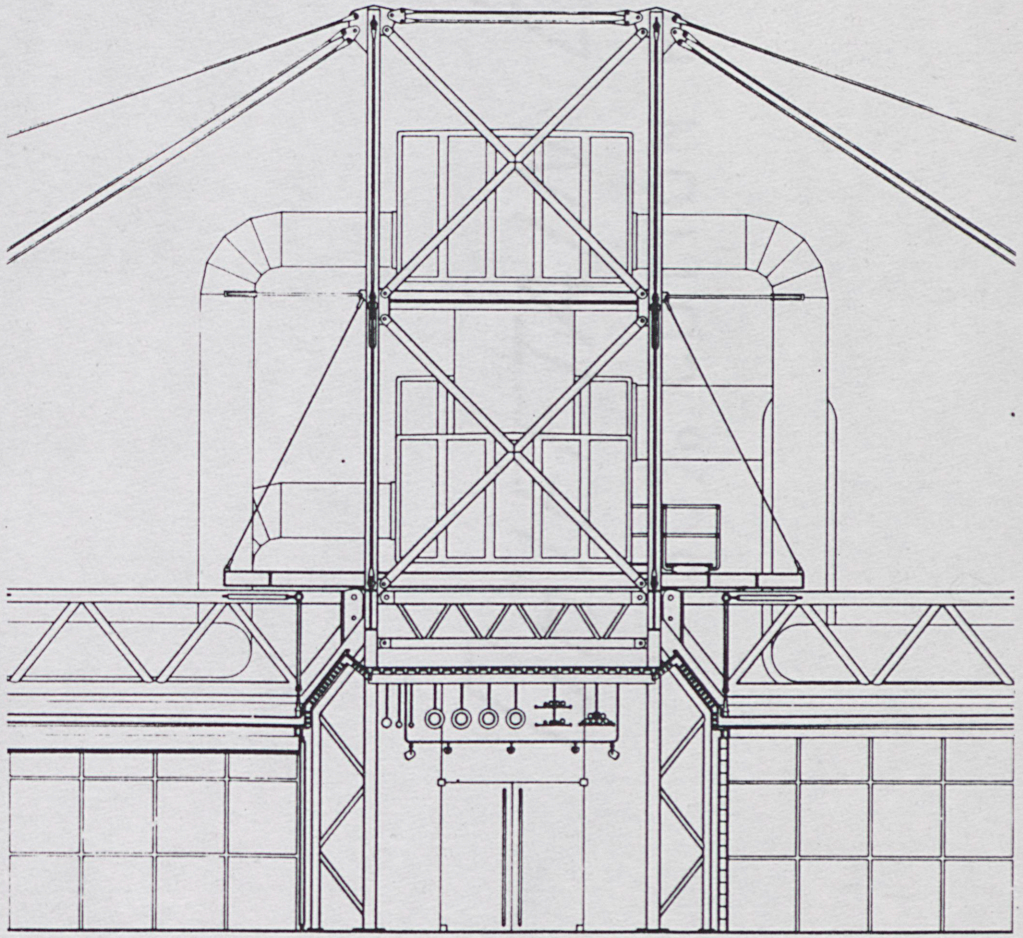
# PRECEDENTS

RICHARD ROGERS PARTNERSHIP

INMOS MICROPROCESSOR FACTORY;
NEWPORT, SOUTH WALES.

SEE BIBLIOGRAPHY NO. 2, P. 27



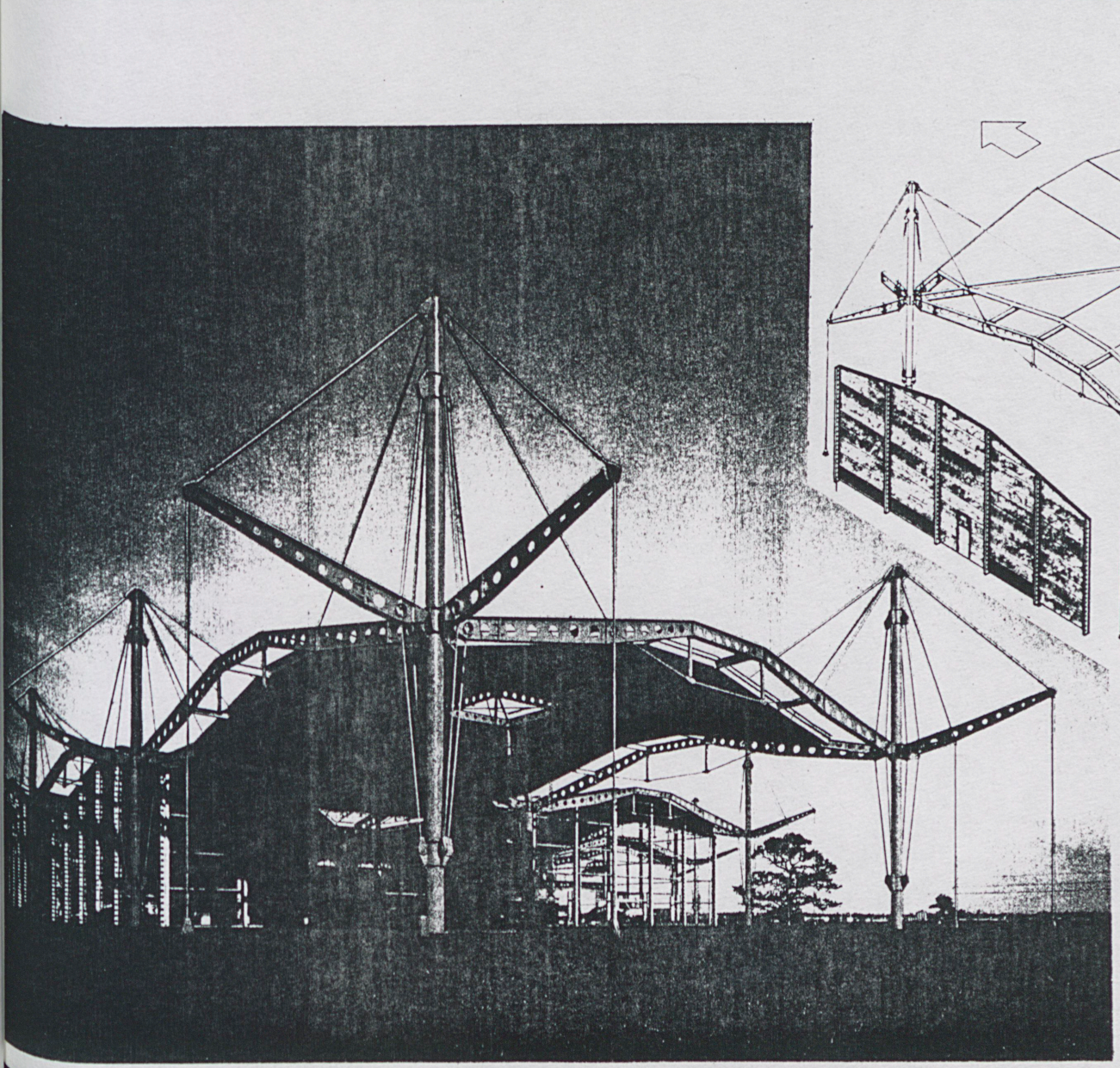


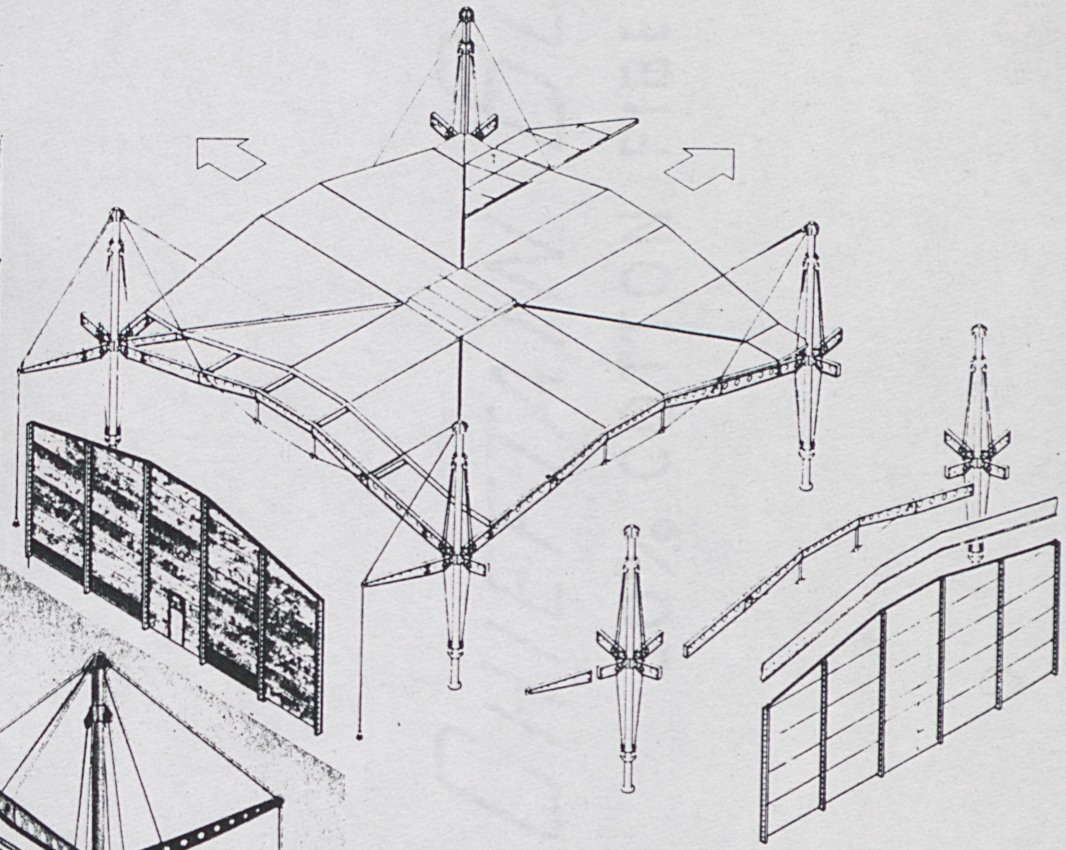
# PRECEDENTS

FOSTER ASSOCIATES

WAREHOUSE AND DISTRIBUTION CENTRE FOR RENAULT; SWINDEN, WILTSHIRE

SEE BIBLIOGRAPHY NO. 2, P. 64





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NICHOLAS GRIMSHAW AND PARTNERS

ICE RINK; OXFORD

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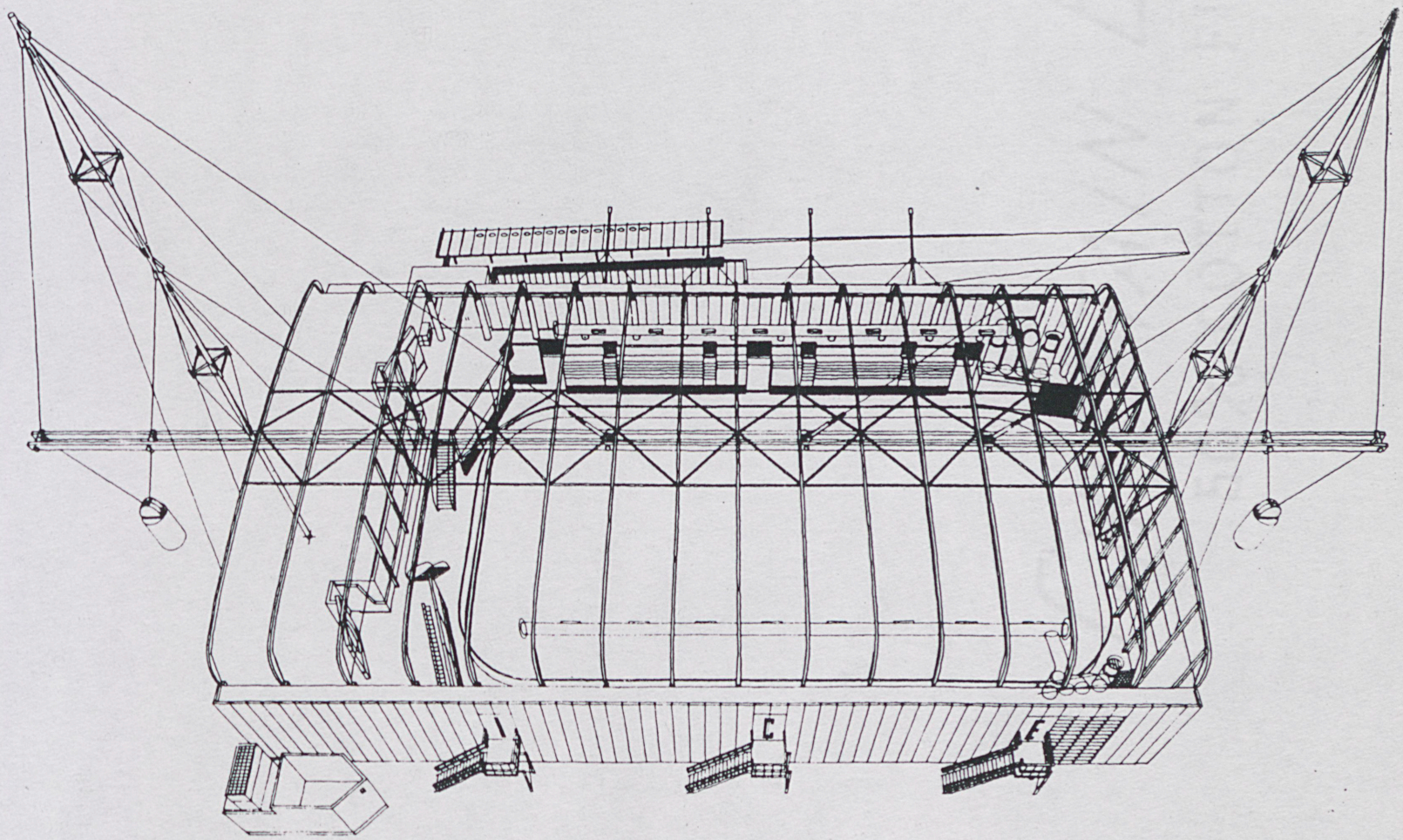

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MICHAEL HOPKINS AND PARTNERS

RESEARCH LABORATORIES FOR SCHLUMBERGER; CAMBRIDGE

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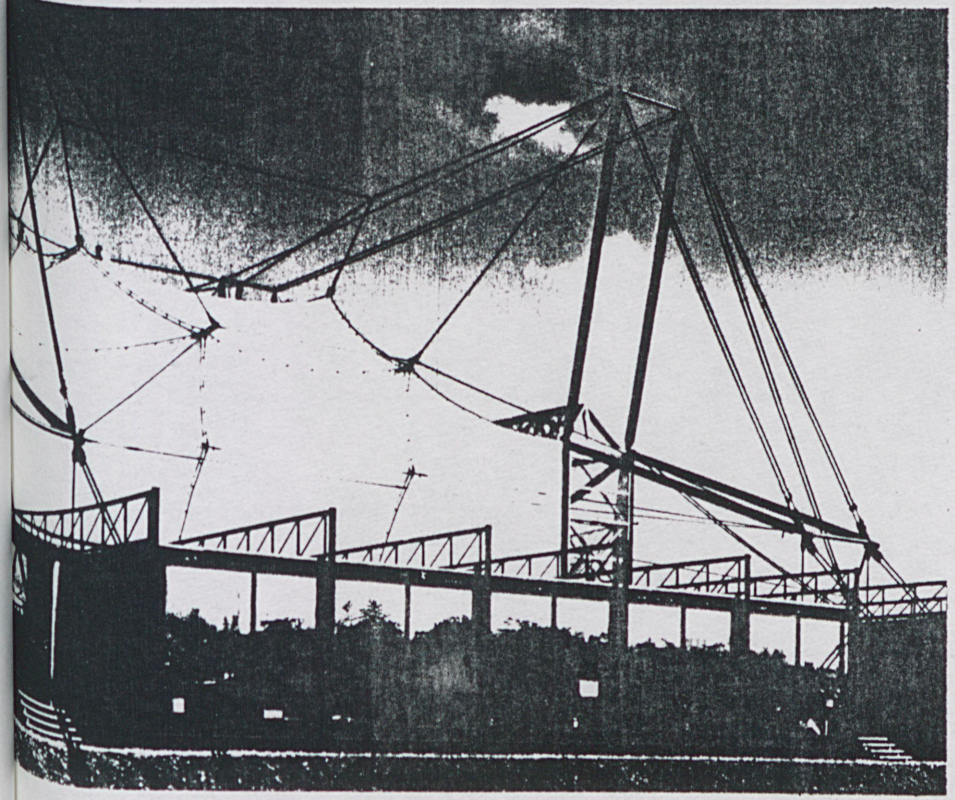

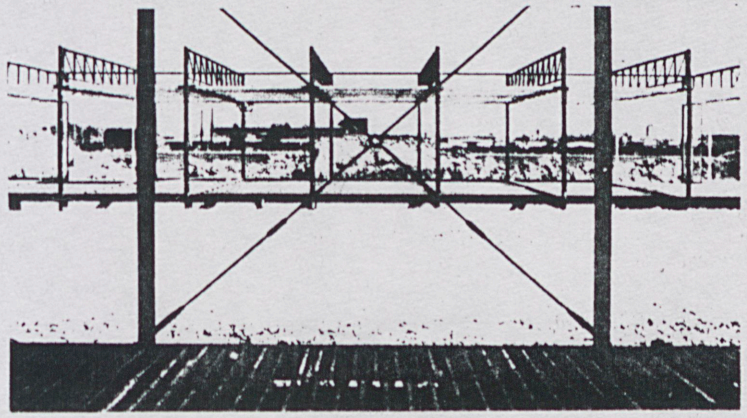

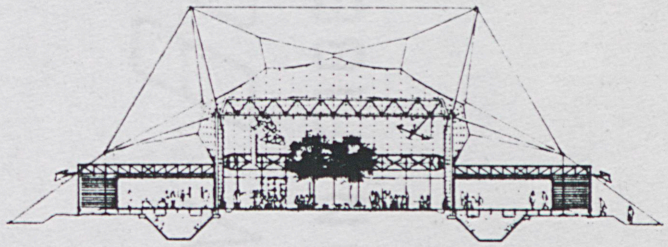

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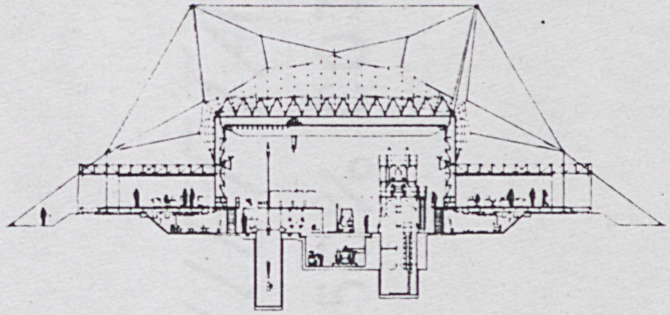

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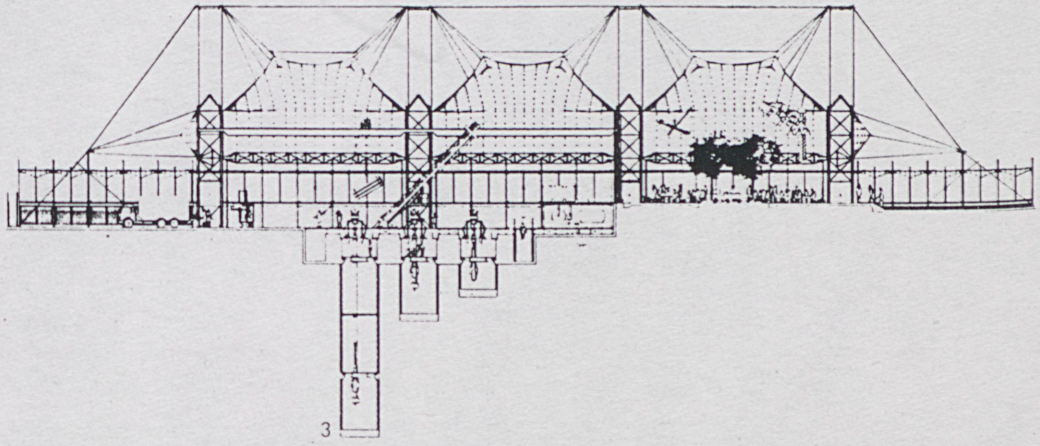

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# SCHEMES

IN DEVELOPING SCHEMATIC OPTIONS FOR A NEW HUNTINGTON BEACH PIER I CHOSE TO DIFFERENTIATE EACH ACCORDING TO ITS HISTORICAL REFERENCE TO THE CONFIGURATION OF THE EXISTING PIER STRUCTURE. THE RESULT OF THIS PROCESS WAS THE EVOLUTION OF THREE SEPARATE SCHEMES:°

SCHEME 1- HISTORICALLY SELF-REFERENTIAL: THE PLACEMENT OF ELEMENTS AND ADJACENCIES OF THE NEW PIER WOULD BE TAKEN DIRECTLY FROM THE CONFIGURATION OF THE EXISTING PIER.

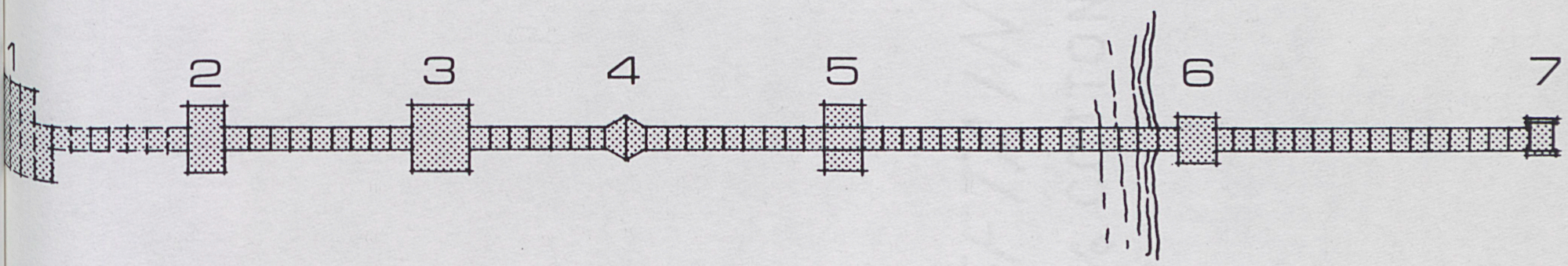
SCHEME 2- ZONING WITH HISTORICAL REFERENCE: THE EXISTING PIER CONFIGURATION WOULD BE RE-EVALUATED ACCORDING TO ZONING OF ACTIVITIES OCCURING ALONG THE PIER. SOME ASPECTS OF THE EXISTING PIER WOULD REMAIN; BUT, THE EXACT ADJACENCIES WOULD NOT NECESSARILY BE PRESENT IN THE NEW STRUCTURE.

SCHEME 3- HISTORICALLY NON-REFERENTIAL: NO ATTEMPT WOULD BE MADE TO INCORPORATE THE CONFIGURATION OF THE EXISTING PIER IN A NEW STRUCTURE (ASIDE FROM PIER LOCATION).

°THE STRUCTURE DEVELOPED IN EACH SCHEME WOULD CONTINUE INLAND ACROSS PACIFIC COAST HIGHWAY AND DOWN MAIN STREET IN THE FORM OF STREET FACILITIES AND FIXTURES.

# SCHEME 1

## HISTORICALLY SELF·REFERENTIAL



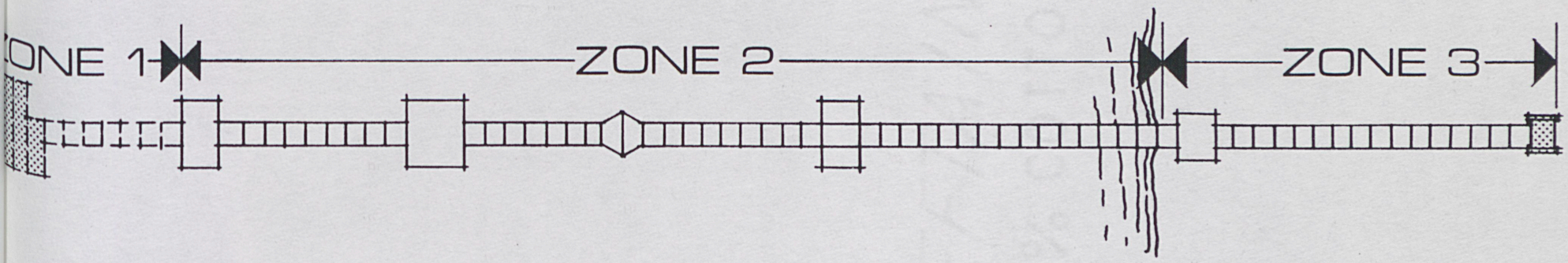

REFERS TO CONFIGURATION OF EXISTING PIER

PROGRAMMATIC ARRANGEMENT WOULD BE IDENTICAL TO THAT OF THE EXISTING PIER:

1. END CAFE
2. FISHING / OBSERVATION
3. PUBLIC RESTROOMS / BAIT SHED
4. FISHING / OBSERVATION
5. MAIN LIFE GUARD TOWER
6. WALK THROUGH PUB / SNACK BAR
7. PIER ABUTMENT

# SCHEME 2

## ZONING WITH HISTORICAL REFERENCE



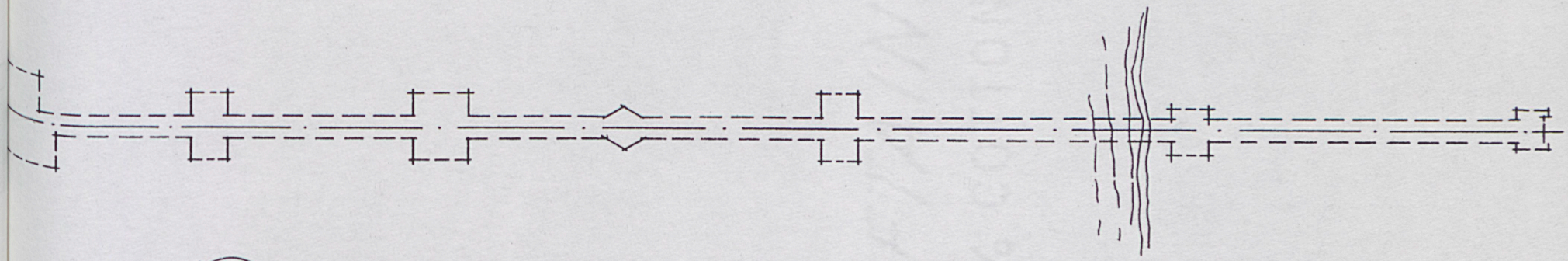

REFERS TO CONFIGURATION OF EXISTING PIER

REFERENCE TO THE EXISTING PIER WOULD BE MADE THROUGH SIMILARITY OF OVERALL DIMENSIONS AND PILING PLACEMENT. PROGRAMMATIC ADJACENCIES WOULD VARY FROM EXISTING PIER:

ZONE 1 - END ZONE: RESTAURANT, OBSERVATION OPPORTUNITIES
ZONE 2 - RECREATIONAL ZONE: LIFE GUARD TOWER, FISHING DECKS, BAIT SHED, PUBLIC RESTROOMS, BLEACHERS AND SEATING AREAS.
ZONE 3 - BEACH ZONE: VEHICULAR RAMP FROM BEACH TO PIER, RE-EVALUATION OF INTERSECTION BELOW PIER OF PEDESTRIAN AND BICYCLE TRAFFIC.

# SCHEME 3

## HISTORICALLY NON·REFERENTIAL



OTHER THAN ITS LOCATION, THE NEW PIER STRUCTURE WOULD MAKE NO HISTORICAL REFERENCE TO THE EXISTING PIER. A DIRECT CONTRAST TO SCHEME ONE, ALL ASPECTS OF THE NEW PIER, FROM PROGRAMMATIC ADJACENCIES TO OVERALL DIMENSIONS, WOULD BE WITHOUT PRECEDENT.

# MATERIALS

THE DISADVANTAGES OF STEEL ARE:

1. HIGH INITAL COSTS.
2. REQUIRES SIGNIFICANT ONGOING MAINTENANCE PROGRAM.
3. PILE CAPS, BEAMS, GIRDERS AND BRACES PAINTED WITH CONVENTIONAL MARINE SYSTEMS REQUIRE PERIODIC PAINTING.
4. AFTER ABOUT 40-50 YEARS THE PILES WILL REQUIRE ADDITIONAL PROTECTION IN THE TIDAL ZONE AND MAY REQUIRE CATHODIC PROTECTION BELOW WATER.°

UPON INSPECTION OF THE POSSIBILITIES OF STEEL AS A PROTECTED STRUCTURAL MATERIAL IN A MARINE ENVIRONMENT I HAVE CHOSEN IT TO BE THE MAIN STRUCTURAL COMPONENT IN MY PROJECT. FOR A FURTHER LOOK AT STEEL AND ITS APPLICATION AND PROTECTION IN MARINE ENVIRONMENTS SEE APPENDIX A.

° THE ABOVE INFORMATION WAS CITED FROM THE CITY OF HUNTINGTON BEACH MUNICIPAL PIER STUDY; PREPARED BY FLOUR DANIEL, INC. JULY, 1988.

# CONSTRUCTION METHODS

THE CONSTRUCTION METHODS COMMONLY USED IN PIER CONSTRUCTION ARE:

1. THE 'OVER-THE-TOP' METHOD IN WHICH CONSTRUCTION ADVANCES OUTWARD FROM THE SHORE WITH THE CRANE MOVING FORWARD OVER COMPLETED PILES TO PLACE THE NEXT PILES | PILE CAP TO THE SEAWARD WITH THE DECKING FOLLOWING BEHIND. THIS METHOD OF CONSTRUCTION IS THE MOST WIDELY USED. THE METHOD DOES, HOWEVER, PRODUCE LARGE CONSTRUCTION LOADS FROM THE CRANE AND LIMITS THE PRACTICAL SPAN LENGTH BETWEEN PILE BENTS.

2. THE 'TRESTLE' METHOD INVOLVES CONSTRUCTING A TEMPORARY TRESTLE ALONGSIDE THE PIER AND CONSTRUCTING THE NEW PIER WITH EQUIPMENT OPERATED ON THE TEMPORARY TRESTLE. THIS METHOD IS GENERALLY MORE COSTLY THAN OTHER METHODS AND IS SELDOM EMPLOYED EXCEPT IN COMBINATION WITH 'FLOATING EQUIPMENT'.

3. THE 'SPIDER' OR 'WALKING PLATFORM' METHOD UTILIZES A CRANE MOUNTED ON A MOVING PLATFORM. WALKING PLATFORMS HAVE BEEN USED IN LOCAL PIER CONSTRUCTION BUT THIS METHOD IS AVAILABLE TO ONLY A FEW CONTRACTORS.

# CONSTRUCTION METHODS

4. THE 'FLOATING EQUIPMENT' METHOD CAN BE USED FOR PART OF THE WORK IN DEEPER WATER. THIS METHOD IS USED IN COMBINATION WITH ONE OF THE OTHER METHODS.

THE 'OVER-THE-TOP' METHOD IS GENERALLY THE MOST ECONOMICAL TO USE... FOR STEEL PILED PIERS WHERE INDIVIDUAL CRANE LIFTS ARE NOT EXCESSIVE AND WHERE WORK CAN PROGRESS RAPIDLY FROM BENT TO BENT.°

° THE ABOVE INFORMATION WAS CITED FROM THE CITY OF HUNTINGTON BEACH MUNICIPAL PIER STUDY; PREPARED BY FLOUR DANIEL, INC. JULY, 1988.

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# APPENDIX A

## STEEL

Steel is a material which has a life long high compressive and tensile strength, but its use in marine structures is limited.

Man's concern with the corrosion characteristics of metals used in maritime works dates to the fourth and fifth centuries B.C. It was observed that while most metals used in ships deteriorated in some way when exposed to sea water, bronze showed little or no corrosion. Since the use of bronze in marine installations is not feasible now or in the near future, methods must be found for protecting the metal most commonly used in these structures, steel, from salt sprays, tidal action, and other environmental factors.

Corrosion refers to the conversion of metals into compound forms as a result of some natural mechanism. The most common types of corrosion are galvanic, differential environment or concentration cells, stray current, bacteriologic, stress, fretting, impingement, and chemical corrosions. Galvanic corrosion requires an electrolyte, sea water, and two dissimilar metals coupled together, one of which will corrode. The corroding area is referred to as the anode, while its counterpart is the cathode. The process involves the flow of current from the anode, which will corrode, to the cathode, which is protected. Certain metals have been used as anodes to steel: magnesium, zinc, and aluminum to name a few. The order in which joined metals in an electrolyte will corrode is determined by the voltaic potential of the metal. Magnesium will corrode to all other metals. Zinc will corrode to all other metals except magnesium. Aluminum will corrode to all other metals except magnesium and zinc, etc. Corrosion producing galvanic cells may occur in the same metal. Steel is anodic to mill scale found on hot rolled steel products such as steel piling. Bright surfaces are anodic to matte surfaces. Stressed surfaces are anodic to normal surfaces. In addition, surface imperfections and non-homogeneous metal may cause galvanic cells.

Differential environment corrosion occurs when a metal such as steel is in contact with an electrolyte which is non-homogeneous from point to point or varies in concentration along the surface of the metal. Some of the major environmental conditions which may cause corrosion cells to develop on steel pilings include varying salt conditions in the soil in contact with the pile, varying moisture conditions in the soil in contact with the pile, different oxygen concentrations in various horizons of the soil or water in contact with the pile, and foreign matter embedded in the soil in contact with the pile such as cinders or pieces of metal. Within the area of tidal fluctuations, the oxygen content varies considerably between the high and low tide levels and the low tide and ground levels. Current flows from the low oxygen to the high oxygen content area resulting in corrosion in the low oxygen or anodic area. Protruding elements, corners, and weld points tend to corrode faster than the surrounding surface metal because the interruption of flow results in development of an oxygen concentration cell. In those areas where fresh water meets sea water, corrosion of steel piles are likely. The higher oxygen content of the fresh water causes current to flow from the salt water area to the fresh water area producing anodic conditions in the salt water and subsequent corrosion of steel pilings in the salt water area.

Stray electrical current corrosion is an electrochemical process similar to galvanic and differential environment corrosion. It is the result of stray electric currents from electric railways, railway signal signs, cathodic protection systems for pipelines or foundation pilings, DC industrial generators, or DC welding equipment. Since metals are more conductive than water or soil, stray currents tend to collect in the metal, following the path of least resistance. Corrosion occurs when the current leaves the metal producing stray current electrolysis at the point where the current exits the metal. While stray alternating currents are generally not harmful to underground or

# APPENDIX A

underwater structures, the current can be rectified by passing through or off metal structures. The partial DC component is then capable of producing current electrolysis, as discussed earlier. The sources of alternating current include central power stations and large substations.

Bacteriological corrosion is caused by two types of micro-organisms, anaerobic and aerobic. Of the two types, the anaerobic is the most responsible for the corrosion of steel. This corrosion results from the creation of concentration cells on the surface of the metal, the creation of a corrosive environment through water and decomposition, and depolarization of cathodic or anodic areas. Corrosion due to this particular type of organisms may be found in bogs, heavy clay, swamps, stagnant waters, and contaminated waters, particularly when contaminated with the waste from paper-making operations. The external corrosion products are black underlain with a thin film of white substance.

Stress corrosion requires high stress in most instances although this may vary with the environment. The stress may be residual stress from cold working, or may be due to applied loads or welding operations. Tensile forces expose metal at the grain boundaries resulting in small intergranular cracks. As the corrosion continues along the grain boundaries, the combination of stress and continued corrosion results in transgranular cracking.

Fretting corrosion occurs on closely fitted metal parts which are under vibration such as a sleeve on a shaft, shrunk metal fittings, or forced metal fittings. The contact surfaces may become pitted and a deposit, usually red in color, may form at the interface. The corrosion damage affects operating tolerances and increases the possibility of failure.

Impingement corrosion affects brass and hard drawn copper and is, therefore, of little concern when dealing with maritime installations.

Chemical corrosion results from the direct attack on steel by acids or diluted acids. Chlorine, carbon dioxide, and sulfur oxide are atmospheric contaminants which may cause the formation of acid films on metal surfaces resulting in rapid corrosion. Chlorine is more commonly found in the marine environment while carbon dioxide and sulfur oxide are common industrial contaminants.

The rate of all of these corrosion reactions is directly affected by the concentration of dissolved oxygen in the water, the concentration of corrosion products in the water, and environmental factors which may affect the condition of the electrolyte such as temperature, salinity, etc. The most rapid corrosion occurs in the tidal fluctuation zone where dissolved oxygen is plentiful and the moving water body prevents saturation of the water surrounding the metal with corrosion products or the deposition of corrosion products on the surface of the metal.

In many instances the failure of a steel structure in sea water could be prevented by thorough design investigations and considerations. These considerations should include the selection of materials to suit the environment, the minimum galvanic potential between two metals, the relative areas of dissimilar metals which are to be joined, the resistivity of the soil and water surrounding the metals, the possibility of applying insulating coatings, and the prevention of water accumulations where feasible. These design criterion may reveal the need for external coatings applied to the surface of the steel members.

Coatings may take many forms: metallic coverings and claddings, organic coatings and wrappings, synthetic organic materials, and concrete casings. Metallic coverings and claddings protect the base metal in two ways depending upon the position of the applied metal in the electromotive force series. If the applied metal is more corrosion resistant than the base metal, the

# APPENDIX A

applied coating is referred to as sacrificial and will corrode to provide protection for the base metal. Sacrificial coatings consist of zinc or aluminum. Organic coatings and wrappings resist moisture absorption and isolate the metal structure over long periods of time from the forces of electricity. Some of the common organic materials used as coatings and wrappings include asphalt, coal tar, paints, plastic wrappings, and greases. Of interest in recent years has been the effect of oil spills on the corrosion resistance on metal structures. Oil films which develop on the structures provide excellent protection from corrosion by isolating the structure from air and water. This method of protection tends to be too costly to be used as a systematic corrosion preventative. Synthetic organic materials have been widely used for electrical insulation and isolation. Plastics are also used in the protection of pipelines from underground corrosion and at the joining points of dissimilar metals to prevent current flow. Concrete casings are the last area of external applied protection. The characteristics of the concrete necessary to insure adequate protection is discussed in the section of this chapter dealing with concrete corrosion. The concrete may take the form of shotcret or gunite but must have a minimum depth of cover of three inches. External coatings tend to deteriorate with age resulting in checking, flaking, scaling, chalking, washing, blistering, peeling, cracking, or spalling. They may, however, be the most economically feasible method of protection for a particular structure.

Cathodic protection refers to the protection of steel or other metals through electrolysis by stray electric currents. There are two methods of cathodic protection, sacrificial and impressed current; each uses a base metal which is corroded instead of the steel in the structure. In the sacrificial system the metal to be protected is wired to a more negative metal and both are placed in an electrolyte, either soil or water. Current flows from the anode to the cathode, from the more negative metal to the less negative metal resulting in the corrosion of the anode and protection of the cathode. Magnesium and zinc are commonly used in the sacrificial system. The impressed current system requires an external power source and anodes consisting of any conducting material suitable for the purpose. Current flows from the anode connection to the power supply to the cathode which is a relative ground. The variable power source provides a wide range of voltage and current possibilities although the entire system is subject to failure due to power failures. The required maintenance and inspection of the impressed system is far greater than that required by the sacrificial system. The sacrificial system is relatively simple to install and maintain. Additional anodes can be added without revamping the design for the entire system. Both systems are effective in protecting those portions of the structure which are constantly immersed in water or imbedded in the ground. Neither system is effective in the splash zone, the area of greatest corrosion, or above water or ground level.

To insure the greatest protection in the splash zone, heavy concrete casings and/or corrosion resistant metal shielding are recommended. Further research into effective corrosion prevention methods should pay special attention to splash zone protection and feasibility of application in areas where little maintenance is likely to be performed.

Good maintenance of the structure can make or break any protection system yet devised. The controlling variables in atmospheric corrosion are the length of time that the metal is wet; the amount of foreign matter in the atmosphere, particularly chlorine, sulfur, and carbon dioxide which form acid films; and the composition of the metal. Proper maintenance can do little as far as controlling the composition of the metal or the foreign matter in the atmosphere, but it can affect the length of time that the structural

# APPENDIX A

members are wet. Structural members can be kept free of dirt and debris which retain rain and wash water as well as the deicing salts which may be present, and may even absorb moisure and corrosive particles from the atmosphere. The water and salts absorbed by the dirt and debris is held in contact with the metal for long periods of time resulting in accelerated corrosion.

Deterioration of a steel structure may result from processes other than corrosion although for fender systems corrosion is of primary significance. Fatigue cracking may occur at connections and points on the structure where a discontinuity or restraint is introduced; at loose connections or members which could force a member to carry unequal or excessive stress; at damaged members, regardless of magnitude, which are misaligned, bent or torn; at sites where corrosion could reduce load carrying capacity through decrease in the member section making it less resistant to both repetitive and static stress conditions; at weld points where crack initiation might begin; at sites of part repair and areas of excessive vibration or unusual twisting; and at places where structural details are known to have exhibited fatigue problems. The effect of high temperatures on steel strength becomes of importance when considering the possibility of fire on a dock or pier structure. During regular operating conditions, the temperatures remain within the realm of elastic design and pose no unusual design problems. Careful inspection of the structure can generally reveal areas of fatigue cracking or plastic failure due to high termperatures.°

°DERLICHER, KENNETH N., AND HEINS, CONRAD P., JR. BRIDGE AND PIER PROTECTIVE SYSTEMS AND DEVICES. (NEW YORK: MARCEL DEKKER, INC., 1979. P. 56-62)

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