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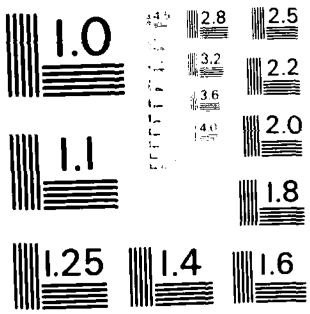

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963

NAVY PIER CONCEPTS
REPORT No. 1/83

THE EXPEDITIONARY PIER

SUBMITTED TO:

■ DEPARTMENT OF THE NAVY

OFFICE OF NAVAL RESEARCH

ARLINGTON, VIRGINIA

SUBMITTED BY:

■ T.Y. LIN INTERNATIONAL

JANUARY 1983

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The expeditionary pier was developed to provide Navy and Marine Corps expeditionary forces operating overseas with the immediate use of full-service piers. These piers can accommodate from four to six ships and have provision for all the services expected from a permanent pier. Present design problems are limited to consideration of the hinge joint and anchoring system. The cost of expeditionary piers would be higher than traditional waterfront construction, but their ability to move with the Fleet is a great benefit.

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TECHNICAL FEASIBILITY STUDY OF PIER CONCEPTS

1. INTRODUCTION

The Navy pier concept study contract for the year 1982/83 called for the continuing development of three selected pier concepts to the point that their feasibility vis-a-vis the state-of-the-art technology may be assessed, and their deficiencies and problem areas identified. The three concepts selected for this study are:

Concept 1 - **The Expeditionary Pier**

Concept 2 - **The Floating Marina Pier**

Concept 3 - **The Mobile Underwater Submarine Base**

Each concept will take up about one third of the contract year that began in September 1982. The results of the year's work will also be presented in a second paper to an engineering conference in or out of the USA.

This report addresses the technical feasibility of the first concept, i.e., the expeditionary pier, and is organized to cover the various study areas as follows:

a. Investigation of the general validity of the design, and the parameters used in the development of the concept. Loading conditions, pier dimensions, structural sizes, flotation characteristics, etc. that were assumed for the original concept will be verified by more detailed analysis and designs during this investigation.

b. Investigation of analytical and design feasibility: The purpose is to determine the adequacy of the state-of-the-art (SOA) technology in carrying out the analysis and the design of expeditionary piers.

c. Investigation of constructional feasibility. Current construction methods that could be used in building the pier will be surveyed and assessed.

d. Investigation and identification of problem areas and technological deficiencies. This will be assessed in relation to their influence and impact on the development of the pier.

2. THE EXPEDITIONARY PIER

To recap, the expeditionary pier was developed to provide the naval expeditionary force operating overseas the immediate use of a full-service pier. To be effective, it should be large enough to accommodate at least four, preferably six, destroyer class vessels. For these purposes, the pier must be self-sufficient, of sufficient size to berth four to six ships, relocatable and rapidly deployable. These features will be discussed below.

2.1 Self-Sufficiency

Self-sufficiency means the pier is equipped to provide full berthing services to navy ships and, if necessary, to enable them to go "cold iron." In addition, it will also carry sufficient quantities of supplies to replenish the ships for long periods of time, perform minor repairs, and provide recreational and training facilities for the ship's crew.

2.2 Berthing Capacity

The berthing capacity of the pier is determined by the size of the ships, the configuration and the size of the pier. Originally, the pier was designed for the future Navy ships, which were conceived to be small, fast and powerful vessels that are produced in sufficiently large numbers to achieve the effect of deterrence. Since the present destroyer class Navy ships are not much longer than the assumed future ship, the pier should provide the same number of berths for the present ships, if it is intended to be used in the near future. As shown, the berthing capacity of the pier for the various schemes is as follows:

Scheme A: Six big ships (destroyer class) and a number of smaller crafts along the central section of the spine pier.

Scheme B: Same as Scheme A

Scheme C: Four big ships plus smaller crafts

2.3 Relocatability

The pier must not only be seaworthy, but also can be moved over long distances at reasonable speeds. Hence, the stream-lined, arrow-shaped configuration, and the retractability of the finger piers in Schemes A and B.

2.4 Rapid Deployability

To be effective, the pier must be quickly operational upon arrival at site. In pursuit of this objective, the stiff-leg, single-point anchoring system has been developed for the use of the expeditionary pier.

3. DESIGN CONSIDERATIONS

The following considerations have been assumed for the preliminary design of the pier, in addition to the four major criteria described above.

a. Materials

Important criteria for the selection of structural materials must include lightness, strength and durability. Available materials that meet these criteria include lightweight concrete and steel. Either material is feasible and available. For the purpose of this investigation, lightweight concrete of 120 pcf density, and prestressing technique are envisaged.

b. **Environmental Loads**

The pier is designed for a wave height of 20 ft, in approximately sea state six, with wind velocity of 90 mph. The wavelength has been assumed to be equal to the length of the pier, for maximum sagging and hogging conditions.

c. **Fendering System**

Modern, fixed-position fendering systems could be used since both pier and ships move together with little variations. In the pier scheme, shown in this report, cell fenders of the buckling cylinder type have been used. These are mounted on the pier and located at such a level that they will always engage the berthing ships at the waterline region away from any hull protrusions.

d. **Self-propulsion**

Although the use of tugs is envisaged in moving the pier, a self-propulsion system on board the pier will be necessary to enable the pier to move under its own power in case of emergency. This system may well be needed to assist the anchoring system in keeping station during severe storm conditions.

4. DESCRIPTION OF THE PIER

The pier is essentially shaped like an arrow to reduce resistance against water during tow or operation. The difference between the three schemes presented herein, Schemes A, B and C, is in the inclusion of the finger piers in Scheme A and B, and the modification to the aft section of the pier in Schemes, B and C. Scheme A, which is the original scheme, has two ships nesting against the back of the pier, i.e., perpendicular to the axis of the pier. In Scheme B, the aft section is modified to have the two ships berth alongside the pier in order to reduce current forces against the pier during operation. Scheme C is similar to Scheme B except it does not have the finger piers. The removal of the finger piers would bring the pier closer to the SOA, and make it more readily available for use in the near-term future.

As mentioned before the pier measures 940 ft in overall length. The hull for all three schemes is 51 ft deep, and when floating with normal live loads, takes a draft of approximately 34 ft., freeboard is therefore 17 ft. The hull is stiffened by structural walls that also serve as watertight bulkheads. Refer to Drawings 1 through 6.

5. VALIDITY OF DESIGN

The first task in this investigation is to confirm the validity of the preliminary design in general for the purpose of subsequent investigations. Specifically, the early design was checked to ensure that its structural system is adequate to withstand the assumed construction, towing and operation conditions, and that its flotation and naval architectural characteristics are satisfactory. Considerable effort has also been made to resolve design problems posed by the two major innovations, i.e., the hinged joint for the finger piers and the stiff-legged swivelling suction anchor.

The results of this confirmatory investigation are contained in calculation sheets appended as Appendix A at the back of this report.

6. ANALYTICAL AND DESIGN FEASIBILITY

The analysis and design of the expeditionary pier as represented in the drawings could be carried out with the state-of-the-art technology. This consists of design guidance provided by the various registration societies and technical and professional institutions. Similar prior design and constructions include the prestressed concrete pontoons that made up the Hood Canal Bridge in the State of Washington, the 460-ft. long prestressed concrete LPG barge that ARCO built for services in Indonesian waters, and the 700-ft. long prestressed concrete container pier now being built for Alaska's port of Valdez. This pier is 100 ft. wide and is made up of two 100 ft. by 350 ft. by 30 ft. deep pontoon units. The units are towed in from a fabrication yard 1,400 miles away, and joined and post-tensioned together upon arrival at the site. The pier is moored to eight hollow concrete gravity anchors each measuring 20 ft. square in plan and 13 ft. deep. The cost of this floating pier project was reported to be $48 million.

The construction of our pier will be similar. It is different from the Valdez pier mainly in size.

Deficiencies in the state-of-the-art technology are present primarily in relation to the two innovations as mentioned before, i.e, the hinge joint for the finger piers and the stiff-legged swivelling single-point mooring involving a suction anchor. These are commented further as follows:

Hinge Joint Between Finger and Spine Piers

The purpose of the hinge joint is to enable the finger pier to be retracted during tow. For easy connection, the joint is located at deck level and consists, as conceived, of a link mounted on the finger pier that is dropped into a pin mounted on the spine pier when the finger pier is manuevered into position. The maximum tension or compression at each of the two connections has been worked out to be in the order of 5,280 kips. Although reversal of stress is unlikely, considerable stress variation that may range from 0 to the maximum of 7,800 kips is possible, and will require that fatigue conditions be considered in designing the joints.

A concept of the hinge connection is shown in Figure 9.

The Stiff-legged Swivelling Suction Anchor

The stiff-legged single point swivelling anchoring system that is developed for the pier is considered most likely to succeed from among the various possibilities. The challenge that is presented to the designer are represented in the requirement that, (1) the system must be capable of developing the unusually large holding force necessary to keep the pier/ship complex and on station and (2) the system can be quickly operational upon arrival at site.

The latter requirement also includes the expectancy of the pier to be able to be retrieved rapidly for quick departure.

These requirements will rule out anchoring systems that require long installation and retrieval times, or anchoring systems that would fix the orientation of the pier thus subjecting it to current forces from all directions. The pier must be made to turn and face the sea at all times in order to minimize the holding force on the anchor. This leaves only the single-point deadman type of anchors for consideration.

A deadman anchor normally consists of a large concrete box, measuring say 25 ft. by 25 ft. on plan, which is filled with ballast such as sand, gravel or lean concrete, after it is lowered to the sea bottom. It is unfortunately not very suitable for the purpose of our pier because of the impracticably large size involved, and the difficulty of recovering the deadman upon departure of the pier from a location. The deadman may have to be cut loose and left behind.

The suction anchor will solve most of these problems because of its relatively smaller size and weight, its large holding power because it invokes the resistance provided by a relatively large body of soil mass, and the short installation and extrication times.

Uncertainties and problem areas are as follows:

1. Application limited only to soils that are penetrable by the suction anchor.

2. Limitation on anchor depth of water. The anchoring system as shown may be applicable to water depths of up to 80 ft.

3. The design of the swivelling joint at both ends of the stiff-leg.

4. The requirement of a swivelling connection to the anchor, for the suction system (or pressure system for the extraction of the anchor) that can rotate around the anchoring system together with the stiff-leg and the pier.

5. The inability of the hinge joint to take large and quick rotational movements.

7. MATERIAL FEASIBILITY

No difficulty is foreseen in using lightweight concrete as the prime structural construction material for the pier. Lightweight concrete can be made in good and consistent quality under the present technology. It has also been proven as suitable material in marine applications. An oft-quoted example is the lightweight concrete ship," SS Selma," which was built during World War I. After the war it was scuttled and sunk in tidal waters in Galvinston Bay. When examined years later, both the concrete and the reinforcement were found to be in excellent conditions even though some of the reinforcement was protected by a concrete cover of no more than half an inch.

The problem concerning material mainly boils down to one of quality control. Secondary problems do exist however. For example, if the pier is stationary in one location for a long period of time, it will have the problem of constantly removing marine growth outside the hull. The concrete could be coated, or additive could be included in the mix that will inhibit marine growth.

Deficiencies in present technology also include the development of fendering materials that can absorb much higher pressure than current practice, to be used in cushioning the impact between the finger and the spine piers. The pier will also need a repair system that can repair all except the most severe damage to the hull, quickly and effectively.

As an extension of the expeditionary pier concept, it will be useful to develop more energy-efficient equipment, possibly solar-powered, that will enhance and prolong the usefulness of the pier on duty overseas.

8. CONSTRUCTION FEASIBILITY

Construction methods are already available to build concrete structures such as the expeditionary pier. Unless a large number of piers are constructed, it can be assumed that the pier, in view of its size, will be constructed in segmental units which are subsequently assembled and joined together to make up the whole pier. The size of the unit is generally limited to 300 or 400 ft. in both horizontal directions. There are several methods of constructing the segmental units. They could be constructed on a special-purpose barge, then launched into the water when completed to a certain stage. Alternatively, they could be built in a shipyard or dry-dock type of facility, on slipways, or in a floor basin, which is the method shown in Drawing Nos. 11 and 12. In this method, the construction site at sea front is excavated so that the base of the site is below the sea level by a depth that is sufficient for the partially completed lower portion of the pier section to be floated out. During construction the sea is kept out by a temporary dike. When the lower portion of the pier unit, which mainly consists of buoyancy chambers, is built, water is allowed into the flood basin to float the unit. The dike is then beached, and the unit towed to deeper sheltered waters where further construction is continued until completion.

Deficiencies in the state-of-the-art technology with respect to the construction of the pier also exist in the areas that had posed difficulties to design and analysis, i.e., the finger/spine pier connection and the single-point suction anchor. Specifically:

1. The hinge joint at both ends of the link that connects the finger pier to the spine pier will provide for rotational movement in the vertical and horizontal directions. However, the joint will not provide for torsional movement between the two piers although some of this movement could be

tolerated by introducing more looseness in the joint. A universal or ball joint will solve this movement problem, but it has yet to be developed for this application.

2. The problem of connecting service lines across the joint

3. The construction of a swivelling joint for the suction hose connected to the anchor, and the problem of controlling the lines to avoid them getting entangled with the other components of the anchoring system as it swivels about the anchor.

4. The joining of the pier units will pose construction problems because of their size. The joining method shown in Figure 7 is the SOA method today. It could conceivably be improved to provide for more tolerances or allow for greater construction variations, and shorter connection time.

5. Quality control. Although this is not a deficiency in the sense thatit is beyond the state of the art, the control of the quality and the consistency of concrete in our case will assume greater importance in view of the magnitude of the construction. A special effort will have to be made to ensure proper and stringent quality control.

9. CONSIDERATION OF ALTERNATIVES

As can be expected, an innovative concept is open for a vast range of possible alternatives, not only of the design relevant to a specific purpose, but also of a great variety of predictable situations for which the pier may be applied. The design as presented for the pier is therefore far from being a finished product. In earlier discussion in this report, three configurations of the pier have been presented, each incorporating modifications that have to do with reducing water resistance, and with removing the finger piers that may not be technologically ready if the pier is going to be constructed in the near-term future.

In view of the considerable size of the pier, it is conceivable that part of it, e.g., the finger pier, could be used as runways for military aircrafts, thus augmenting the role of the pier as a quasi-aircraft carrier. Figure 13 shows how the finger piers will look after their conversion into runways. By confining the runway to the forward part of the finger pier, it would still be possible to provide two berths along the lee side of the pier, thereby maintaining its berthing capacity to four destroyer class vessels in spite of the conversion. There is ample space below deck for the storage of planes and supplies to support the pier in this additional role.

10. CONCLUDING REMARKS

This investigation has shown the technological feasibility of an expeditionary pier that can be readily deployed to provide the full berthing facilities and services to Navy ships operating overseas. The cost of such a pier will be high. However, its availability will provide the Navy with a new option in its operation overseas, the value of which cannot be determined solely in terms of cost.

The development of the full pier, i.e., as shown in Scheme A or B, will depend on the successful development of two major innovations, i.e. the connection between the finger piers and the spine pier, and the stiff-legged swivelling suction anchoring system. These innovations and the problems they pose can be solved with additional efforts and time, part of which may run parallel to the further development of the pier itself. They should not in any case hamper the development of the pier, since at worst, these difficulties could be removed by supplementing them with systems that are already within the state of the art. For example, the incorporation of a dynamic positioning system to supplement whatever conventional anchoring system that may be used, instead of the innovative stiff-legged swivelling mooring as conceived. What it boils down to is whether there is a need for such a pier. If there is, there is sufficient reason to believe that the pier could be developed, designed and constructed based on the state-of-the-art technology in a matter of a few years.

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
[illegible]

PROJECT:	Navy Piers
ITEM:	Expeditionary Pier
DESIGN:	Summary
DATE:	[illegible] 82 [illegible]

SHEET: A-1
OF
REVISION:

APPENDIX A

EXPEDITIONARY PIER SCHEME A

Operating Speed : 6 Knots

GEOMETRY

Size : 940' x 170' x 150'
Weight : 139,000 Tons
Draft : Light Ship : 98'
Live Load : 142' [illegible]
Total 240' Decks

Center of Gravity : x = 440' From aft
y = 325' From bottom slab

Center of Buoyancy : x = 434' From aft

Spine roll period : 10.3 sec
Spine pitch : 26 sec

Finger roll period : 3.7 sec
Finger pitch : 6.2 sec

LOADING

Sea State 6
Max wave height : 20'
Wind velocity : 50 knots
Current velocity : 3 knots
(Finger and Spine design)
Current velocity : 4 knots for towing

MATERIALS

Light weight concrete 125 PCF
$f'c$ = [illegible] psi (Spine Pier) and $f'c$ = 7000 psi (Finger)
Prestressing steel : Uncoated seven wire strand
ASTM A416 [illegible] — fpu = 270 psi
Reinforcing steel : ASTM A615 Grade 60
Mild Steel : ASTM A572 Grade 50

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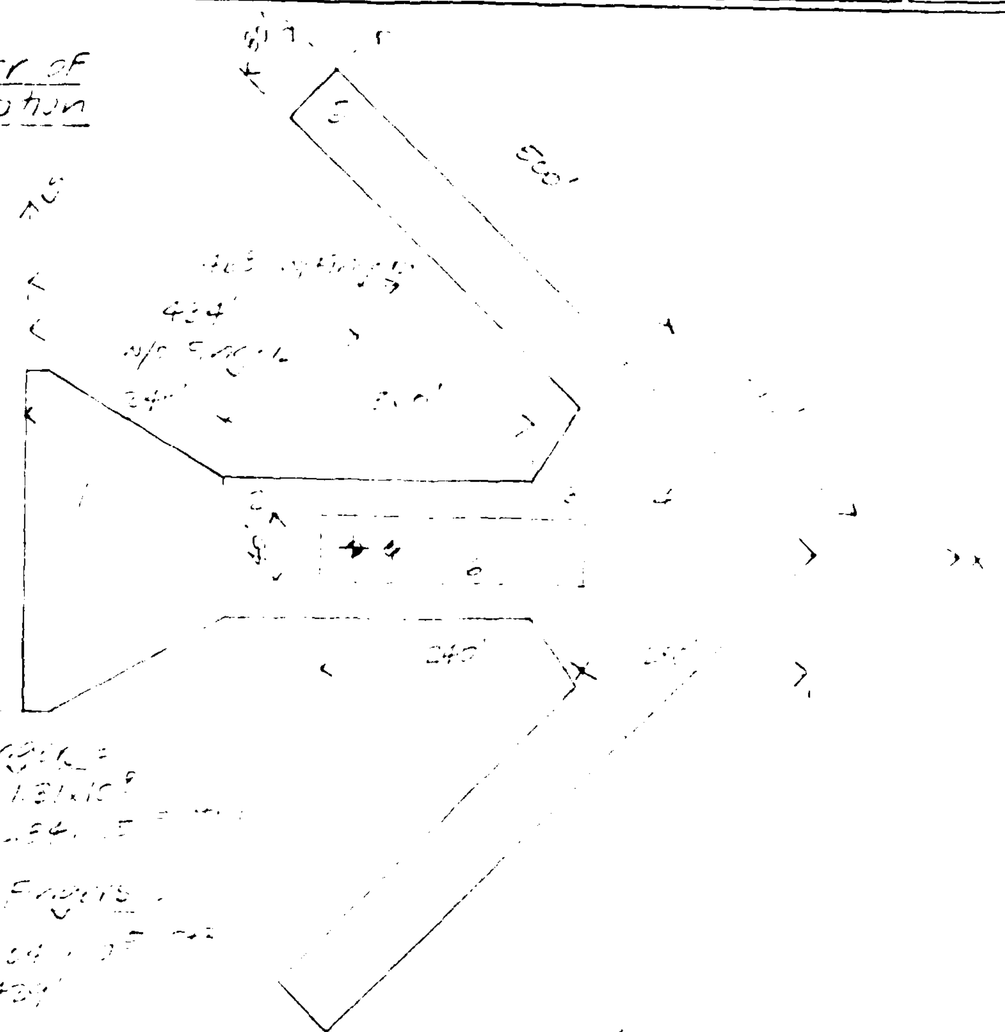
PROJECT	Navy Piers
ITEM	Expeditionary Pier
DESIGN	Center of Flotation
DATE	[illegible]

SHEET 4-2

Center of Flotation



w/ Fingers =
$\bar{X}_1 = \frac{1.31 \times 10^8}{2.54 \times 10^5}$ = [illegible]

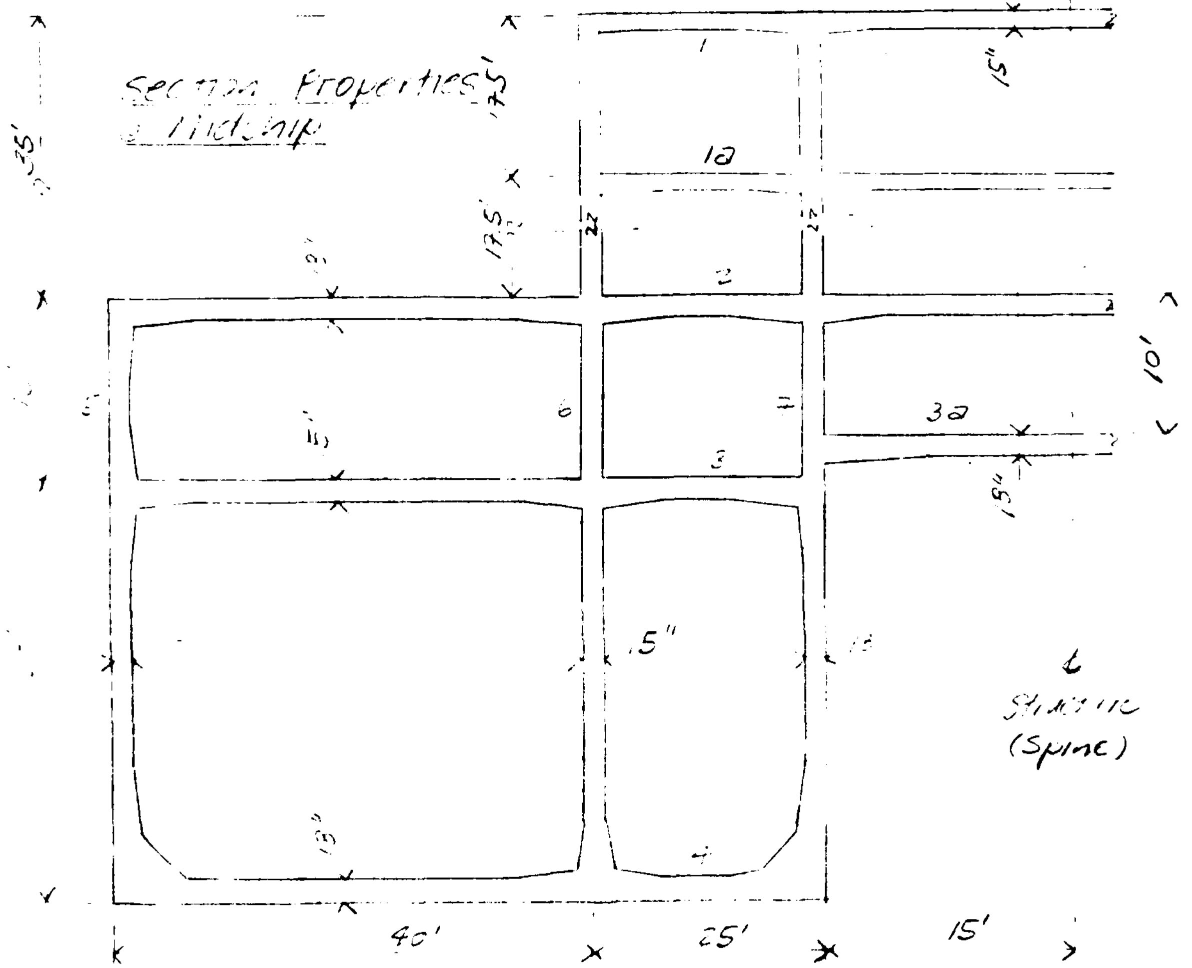
w/o Fingers
A_2 = 2.54 × 10^5 [illegible]
$\bar{X}_2$ = 429'

	Area	x	Ax (ft³)	Ax² (ft⁴)	I₀ (ft⁴)
1	74400	[illegible]	[illegible]	7.9 × 10^8	[illegible]
2	57600	420	[illegible]	1.02 × 10^10	6.22 × 10^8
3	[illegible]	[illegible]	[illegible]	[illegible] × 10^10	[illegible] × 10^7
4	[illegible]	[illegible]	[illegible]	[illegible]	1.30 × 10^8
5	[illegible]	[illegible]	[illegible]	[illegible]	4.07 × 10^7
6	− [illegible]	240	[illegible]	− 2.9 × 10^9	− 46 × 10^6
Σ	2.54 × 10^5		1.31 × 10^8	7.8 × 10^10	1.90 × 10^9

$\bar{I}_1 = 7.99 \times 10^{10} - 2.54 \times 10^5 \times 401^2 = 1.95 \times 10^{10}$ Ft⁴
$\bar{I}_2 = 5.53 \times 10^{10} - 2.54 \times 10^5 \times 429^2 = 1.85 \times 10^{10}$ Ft⁴

T.Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca 94133	PROJECT Navy Piers ITEM Expeditionary Pier DESIGN [illegible] @ Midship DATE [illegible]	SHEET A-[illegible] OF REVISION

Section Properties @ Midship



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						40.3	23837

3322756
−236[illegible]343

I_{ox} = 9[illegible]313

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PROJECT	Navy Piers
ITEM	Expeditionary Pier
DESIGN	ABS [illegible] wave moments
DATE	[illegible]

SHEET A-4

[illegible] Allowable Bending Moment

[illegible] Allowable Bending Moment [illegible]

[illegible]

2490 [illegible]

[illegible] 0.45 F'c 2

465 [illegible] F'c = 7500 [illegible]

[illegible]

M_a = [illegible] 1463 [illegible] 2490 = 4.52 (5.22) × [illegible] k-F

[illegible]

[illegible] bending moment:

$M_t = M_{sw} + M_w$

M_{sw} = Still water bending moment [illegible]

M_w = [illegible] wave-induced bending moment
= $C_2 L^2 B H_e K_2$

[illegible] for [illegible]

C_2 = [illegible]

[illegible] = [illegible]

L = [illegible]

B = 16 [illegible]

H_e = Effective wave height of standard wave in Ft.
= $[4.5L - [illegible] L^2 + 325] \times 10^{-2}$
= [illegible] 720 < L < [illegible] Ft.

M_w = [illegible] × 2650 × 1.0 × .24 [illegible]
= 5.5 × 10 [illegible] K-FT

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PROJECT	Navy Piers
ITEM	Expeditionary Pier
DESIGN	Allowable Wave Height
DATE	[illegible]
SHEET	A-5
OF	
REVISION	

Determine Allowable Wave Height by Proportion

Allow. H / Max Me = He / Mw

At [illegible] H = Me / Mw × He

= 4.52 × 10^6 [5.22] / 5.8 × 10^6 × 26.6' [23.9'] = 20.7' > 20' satisfactory Sea State 6

Use ABS Rules to Determine Allowable Wave Height For Shorter Pier Length:

For L = 900'

[illegible]

= 26.4'

Mw = 6.9 × 10^-4 × 900^2 × 160 × 26.4 × 1 × 1.24

= 5.23 × 10^6 k-ft

H = 4.52 [5.22] × 10^6 / 5.23 × 10^6 × 26.4' [26.4] = 22.8 wave

Determine Maximum Allowable Moment by Proportion:

Mmax = H / He × Mw   H = 20'

= 20' / 20.7' [.56] × 5.8 × 10^6 = 5.6 × 10^6 k-ft [4.4]

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PROJECT:	Navy Piers
ITEM:	Expeditionary Pier
DESIGN:	Sling Pier Loading
DATE:	[illegible] RM

SHEET: A-6
OF
REVISION:

ABS Wave Bending Moment and Shear Distribution

$M_{max} = 5.6 \times 10^6$ K-F L = 940', Stations @ 94'

Station	Bending Moment (wave height = 20')		K-F
0	0	=	0
2	0.10 × 5.6 × 10^6	=	560000
4	0.35 × 5.6 × 10^6	=	1960000
6	[illegible].68 × 5.6 × 10^6	=	3808000
8	[illegible]95 × 5.6 × 10^6	=	5320000
10	1.0 × 5.6 × 10^6	=	5600000
12	.94 × 5.6 × 10^6	=	5264000
14	.74 × 5.6 × 10^6	=	4144000
16	.43 × 5.6 × 10^6	=	2408000
18	[illegible] × 5.6 × 10^6	=	728000
20	0	=	0

Shear Force

Station		K
0	0	= 0
2	560000/94 [illegible]	= 11915
4	(1960000 − 560000 − 11915×94')2/94 + 11915	= 17872
5	.43 × 940' + 17872	= 18295
6		= 17872
8		= 11915
10	0	= 0
12		= 11915
14		= 17572
15		= 18295
16		= 17572
18		= 11915
20	0	= 0

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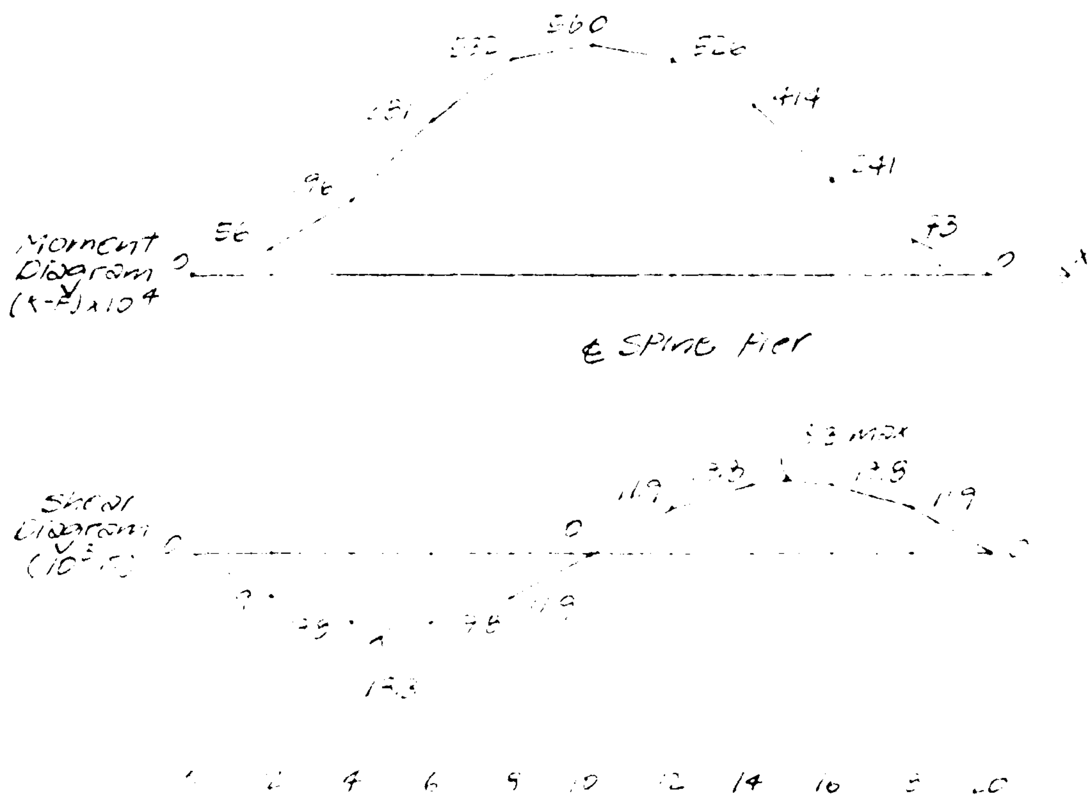
PROJECT: Navy Piers
ITEM: Expeditionary Pier
DESIGN: Spine Pier Loading
DATE:

SHEET: 4-7
OF
REVISION:

Wave Moment and Shear Envelopes



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STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca. 94133

PROJECT:	Navy EIS
ITEM:	Expeditionary Pier
DESIGN:	Wave Pier Loading
DATE:	[illegible] 82 KM

SHEET: A-8
OF
REVISION:

Spine Pier Loading : [illegible] controls

Primary Stresses $M_{max} = 5800000$ K-F

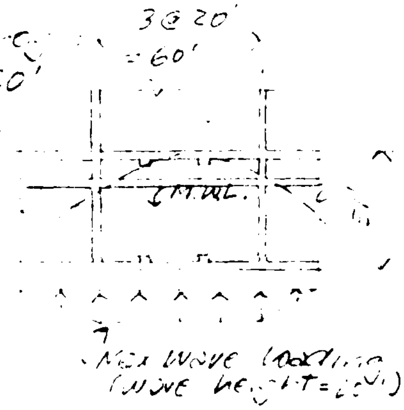
$\sigma_{top} = 5800000 / 2490 = 261^{KSF} = 1810^{psi}$ (T)

$\sigma_{bot} = 5800000 / 3637 = 174^{KSF} = 1021^{psi}$ (C)

Secondary Stresses @ Bottom Slab : (+3.0')

a) At bottom slab due to buoyancy (3@20' = 60')
longitudinal slab span 20'
Dead Load :
Concrete .21/12 · 2 = 0.21 K/'
Mech + Misc. = 0.10
Buoyancy = .064 · 35 = 2.20

Resultant = -2.81 K/'
no live load (1/3 supp)
max. compress



Slab Section Properties :

At Support t = 24" (increased @ mid-third of pier)
I = [illegible] ft^4
S = [illegible] ft^3

b) Moment : Ln = 18'   L = 40'
L/Ln > 2.0 → one-way slab

$M_{max} = W L_n^2 / 14$
$= 2.81 \times 18^2 / 14 = 65$ K-F

Stress $\sigma = 65 / 0.67 \times 1.33 = $ [illegible] KSF
$=$ [illegible] PSI (±)

Secondary Stresses @ Top Slab : (+55.0')

a) Loading :
Dead Load : Concrete : 8/12 · .15 = 0.10 K/'
Mech + Misc = 0.10
Live Load : @ 400 PSF = 0.40

Total Load = 0.68 K/'

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
3'5 Ba, St. San Francisco, Ca. 941??

PROJECT:	Navy Pier
ITEM:	Expeditionary Pier
DESIGN:	Spine and ting Stresses
DATE:	?/ 82 KM

SHEET: A-9
OF
REVISION:

Cont' Spine Pier Stresses @ Top Slab:

1) Moment @ Support $M = wLn^2/11$ $Ln = 19'$
$L_1/Ln > 2.0$ $L_1 = 40'$

$= 0.68 \times 19^2/24 = 15$ ...

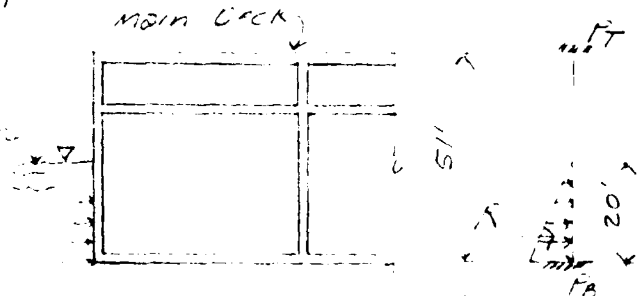
Slab Cross Section, $t = 18''$ assumed @ support
$I = $ ... F^4
$S = $ ... 35^{F3}

2) Stresses, $f = $ ... 8 $/0.28 = 45^{KSF}$ $= 320^{PSI}$ $(\pm)$

Additional Compression Stresses due to Water Head:

1) Salt Water

a) Dead load only, for maximum tension
Draft = 19.5'



Spine Longitudinal Sect.

Resultant Compression Force: $R = 0.064 \times 20^2/2$
$= 12.8^{K/I}$

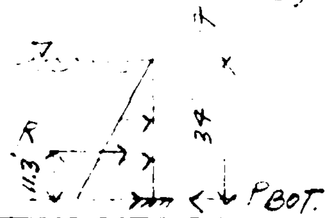
$P_T = 12.8 \times 20/3/51'$
$= 1.67^{K/I}$

$P_B = 12.8 - 1.7$
$= 11.1^{K/I}$

Consider bottom only as Top loading is taken by Main deck which is not the critical one.

Stress $P/A = 11100/12 \times 12 = 77$ psi

b) Live load + Dead load
Draft = 34'
Resultant = $0.064 \times 34^2/2 = 37^{K}$



$P_{BOT.} = 37 \times 39.7/51' = 29^{K/I}$
$P_{TOP} = 37 - 29 = 8^{K/I}$

Cont' Still Water Head Stresses:

Stresses due to Live + Dead loads draft:

At support: σ_{BOT} : 29000 / 24x12 = 101 psi

σ_{TOP} : 4000 / 18x12 = 37 psi

2) Wave Induced Water Head Stresses:

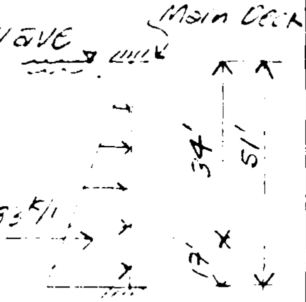
Assume avg. wave height of 20'

Total Water Head: Dead + Live loads + Wave

= 51' max

Resultant = $0.064 \times 51^2/2$

= 53 k/l



Ptop = 53 x 17'/51' = 18 k/l

Pbot. = 63 x 34/51 = 35 k/l

Stresses: σ_{BOT} = 55000 / 24x12 x 1/13 = 144 psi

Combination of Stresses:

	Max. Tension (psi)		Max. Compression (psi)	
	Longitudinal	Transverse	Longitudinal	Transverse
Primary	1810		1631	1631
Secondary	320	320	521	—
Σ	2130	320	2152	1631
Water head		-	+ 144	+ 144
Total Max.	2130	320	2296 ✓	1775 ✓

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St. San Francisco, CA [illegible]

PROJECT:	Navy Piers
ITEM:	Experimentary Pier
DESIGN:	Slab Pier Prestressing
DATE:	[illegible] AM
SHEET:	A-11
OF	
REVISION:	

Longitudinal Prestressing:

Partial [illegible] assume 40% of prestress necessary to offset tensile stresses due to general loading. [illegible] being taken by untension [illegible].

[illegible] Area: Assume prestress [illegible] of total cross-area
[illegible] = 1336 SF → increase of 9% [illegible] area

Prestress [illegible] = 162 KSI

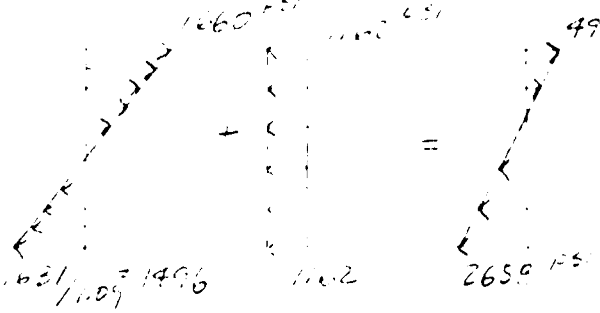
[illegible] = 16 [illegible] KSI

[illegible] = 495 PSI (mild steel)

Final Stresses [illegible] Prestressing (compression)

Stress (psi)	Longitudinal	Transverse
General Loading (Dead + Prestress)	[illegible] 1658	2793
[illegible]	[illegible] = 665	144
Σ (PSI)	3323	2937

f'c required = 3323 / .45 = 7384 psi
[illegible] = 7500 PSI, lightweight concrete



Total Prestressing Force:
$1162 \times 144/1000 \times 1456^{SF}$
$= 243\,630^{K}$ FORCE

Wave loading + Prestressing = Final Primary Stresses

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca 94133

PROJECT	[illegible]
ITEM	[illegible]
DESIGN	Weight of [illegible]
DATE	[illegible]
SHEET	A-12
OF	
REVISION	

[illegible]

[illegible] :

[illegible]

$= 12784^k$

Topping [illegible] $= 0.045 \times \frac{2}{12} \times$ [illegible] $= 1652$

[illegible] $=$ [illegible]

Transverse wall $= 0.120 \times 15$ [illegible]

$= 1750$

Total $= 91446^k$

[illegible] Area $= 34400 + $ [illegible] $= 75800$ [illegible]

[illegible] $= 0.120 \times$ [illegible] $=$ [illegible]^k

[illegible]

[illegible] $= 17975^k$ [illegible]

[illegible] $= .150$ [illegible]

$+ 360) \times 47'$ $= 9165^k$

[illegible] $=$ [illegible] $) \times 47'$

$=$ [illegible]

[illegible] $=$ [illegible]

$=$ [illegible]^k

[illegible]

[illegible] $40 + 420$ [illegible] $= 9175^k$

Total [illegible] $= 145812^k$

Top [illegible] $=$ [illegible] $\times 75800 = 1074^k$

[illegible] $=$ [illegible] $\times 3 = 26740^k$

Σ [illegible] $= 166590^k$

Total [illegible] $= 91446 + 166590 = 258336^k$ ←

[illegible] :

[illegible] $= 7200$

[illegible] $=$ [illegible]

[illegible] $=$ [illegible]

(assumed [illegible]) Total [illegible] 232328^k ←

Total [illegible] $= 490664^k$ ←

T.Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca 94133	PROJECT [illegible] ITEM [illegible] DESIGN Roll Period DATE [illegible]	SHEET A-13 OF REVISION

Roll Period:

Lift:

[illegible] 5336^K [illegible] = [illegible] 8

Total Lift (TL + LL) = [illegible] + [illegible]

19.5' - 17.8'

= 37.0' ← d

Vertical Center of Gravity H under Full Load:

H = (9 440 [illegible] + [illegible]) / 490664

H = 19826932 / 490664

40.4' from base line

Center of Buoyancy:

KB = 40.4/2 = [illegible] About Base line

[illegible]

[illegible] = 490664 / [illegible] (204000 × 37.6 × 224/5)

[illegible] height

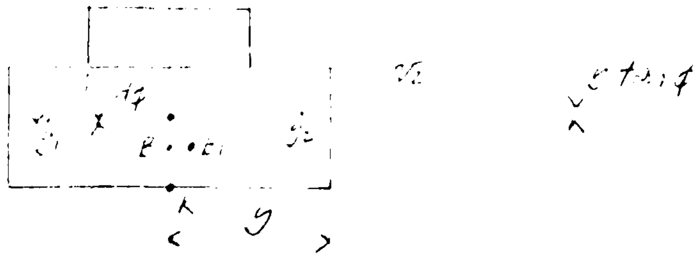


FIG.

T.Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca 94133	PROJECT [illegible]	SHEET A-14
	ITEM Expeditionary [illegible]	OF
	DESIGN Roll Period	REVISION
	DATE [illegible]	

$\overline{BM} = \frac{[illegible]}{[illegible]} = \frac{\nabla \times [illegible]}{\nabla \times [illegible]}$ ∇ volume of Displacement

= 5L

∇ = volume of [illegible]

[illegible] angle ϕ =

[illegible] = 204000# [illegible] = 217'

∇ = [illegible] = .0[illegible] × 27.[illegible] = 7.07 × 10 (FT³)

[illegible] = 19.5'

$\overline{KM} = \overline{KB} + \overline{BM}$

[illegible] = 20.2'

$\overline{GM} = \overline{KM} - \overline{KG}$

[illegible] = 40.4'

[illegible] Period $T = \frac{C B}{\sqrt{GM}}$ B = 175'

C = .52 [illegible] for Pontoon

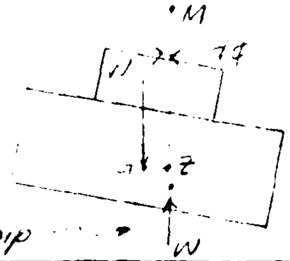
ϕ	[illegible]	∇ (FT³)	(FT⁴)	$\overline{BM}$ (FT)	$\overline{KM}$ (FT)	$\overline{GM}$ (FT)	Tϕ (SEC)
10°	[illegible]	7.07 [illegible]	4.99×10⁵	10.5	185	3.5	9.9
5°	.09	7.07× [illegible]	4.99×10⁵	10.5	175	3.5	10.0 ←
1°	[illegible]	[illegible]		10.5			

Righting Moment [illegible]:

$M_R = W \times \overline{GM} \times \sin \phi$ W = weight of Ship

$= 490664 \times 1.48'$ $\overline{GZ}$ = Righting arm

$= 726183$ K-F $= \overline{GM} \sin \phi = 1.48'$



T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca 94133

PROJECT	[illegible]
ITEM	[illegible]
DESIGN	[illegible]
DATE	[illegible]
SHEET	A-15
OF	
REVISION	

$\overline{BM_L}$ = [illegible] / 7 [illegible]

[illegible] = 10°

[illegible] $= 4226143$ [illegible]

$V = 2{,}4000 \times 57.6 \times$ [illegible] $= 7.67 \times 10^6$ [illegible]

[illegible]

$\overline{BM_L} = \dfrac{4226143 \times \ldots}{7670000} = 345'$

$\overline{KM} = 20.2' + 345' = 365'$

$\overline{GM} = 365 - 40.4 = 325'$

pitch = [illegible] / 325 = [illegible] sec.

$\phi = 10° \longrightarrow$ [illegible] $- 27$ sec.

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca 94133

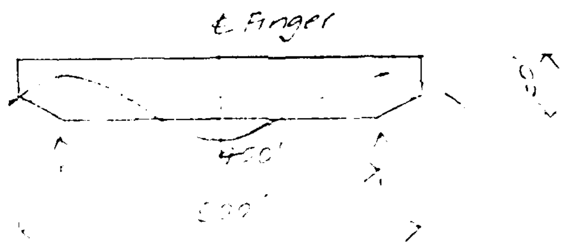
PROJECT	Navy Piers
ITEM	Expeditionary Pier
DESIGN	Finger
DATE	1/30 KM
SHEET	A-16
OF	
REVISION	

Finger Piers

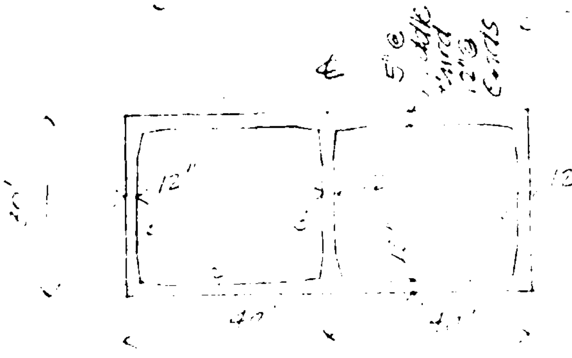
[illegible] fingers [illegible] [illegible] structures as [illegible] forces [illegible] from [illegible] finger pier [illegible] forces [illegible] forces [illegible] of the [illegible] in the design [illegible] connections.

[illegible] Sea State 6
Max. Wave height = 20'
Max. Wave length = 400'

Sagging / Hogging



Section properties [illegible]:
[illegible] = 30' [illegible]



	A	y	Ay	Ay²	I
1	96	29.4	2820	82908	[illegible]
2	[illegible]	5.03	60	33	[illegible]
3	90	15	1350	20025	3750
Σ	282	15	4230	109927	
				63450	
				46477	

15

$S_t = S_b = \frac{46477}{15}$
$= 3098\ ft^3$

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca 94133

PROJECT	Navy ...
ITEM	Finger Design
DESIGN	Wave ...
DATE	...

SHEET A-17
OF
REVISION

Environmental Loads

... Primary Stresses

Finger piers ... built in two stages. Built one ... first ...

Maximum ... will occur while pier is in service. That is in the open ocean design. Finger pier for 20' high, 400' long wave. (See ...) in addition to forces caused by salt water environment.

Total Bending Moment: ABS Rules Section 6.5.2)

$M_t = M_{sw} + M_w$

M_{sw} = ... bending moment ... structure ... approximately uniform. ... service conditions ... acting along with the maximum ... forces.

M_{sw} = ...

... 0.5 ...
$= ... \times 10^4$
... 181,500 ... 11,500
$= 20.51$

M_w = ... 4,500 ... 0.24 ...
$= ...340 ...$ K-F

Maximum Allowable Bending Moment:

$M_{all} = \sigma S$

σ = Max. allowable compressive stress ksi

$f'c = 6500$ psi

$\sigma = 0.45 \times 6,500 = 1.463$ ksi
$= 211$ ksf

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca 94133

PROJECT	Navy Piers
ITEM	Expeditionary Pier
DESIGN	[illegible]
DATE	[illegible]
SHEET	A-18
OF	
REVISION	

Cont' Max Allowable Bending Moment :

$S_T = 3098$ Ft^4

$M_{all} = 211 \times 3098 = 653678^{k-F}$

Determine Allowable Wave Height By Proportion :

$$\frac{Allow.\,H}{Max\,Mt} = \frac{Hc}{Mw} \rightarrow H_a = \frac{Mt}{Mw} \cdot Hc$$

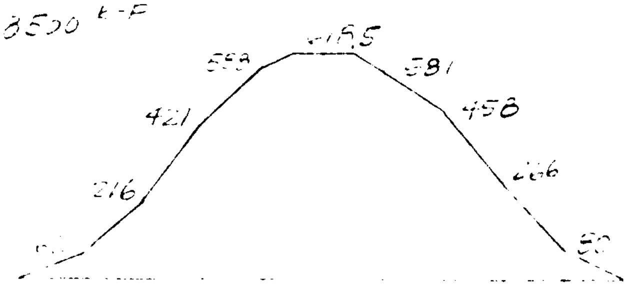
$H_a = \frac{653.78}{634000} \times 20.5' = 21.1' > 20'$

The [illegible] height is above the limit of Sea State 6

For $H = 20' \rightarrow M_{max} = \frac{20}{20.5} \times 634000 = 618537^{k\cdot F}$ <

ABS [illegible] Bending Moment Distribution : Table 6.1

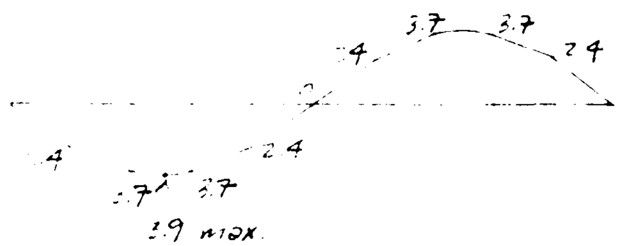
$M_{max} = 618500^{k-F}$



Moment Diagram
$(k\text{-}F) \times 10^3$

> X

℄



Shear Diagram (10^3 k)
(See next page)

TY-IN INTERNATIONAL STRUCTURAL ENGINEERING, 315 Bay St., San Francisco, Ca 94133	PROJECT: [illegible] PIER ITEM: [illegible] DESIGN: [illegible] DATE: [illegible]
SHEET A-19 OF ____ REVISION	

[illegible] (k-ft)

Station — Bending Moment (wave height = 20')   k-ft

Station			Moment
[illegible]	0	=	0
[illegible]	[illegible] × 618500	=	[illegible] 850
2	[illegible] × 618500	=	216475
[illegible]	[illegible] × 618500	=	420580
[illegible]	[illegible] × 618500	=	587575
[illegible]	[illegible] × 618500	=	618500
[illegible]	[illegible] × 618500	=	551390
7	.74 × 618500	=	457690
10	[illegible] × 618500	=	365955
15	[illegible] × 618500	=	30405
[illegible]		=	0

Shear Force (k)

Station			Shear
0	0	=	0
2	(61850/[illegible]) 2	=	2474
4	[(216475 − 61850 − 2474 × [illegible]) [illegible]] − 2474	=	3711
5	[illegible]45 × 500' + 3711	=	3936
6		=	3711
[illegible]		=	2474
10		=	0
12		=	2474
14		=	3711
15		=	3936
16		=	3711
18		=	2474
20		=	0

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca 94133

PROJECT: [illegible] Piers
ITEM:
DESIGN: Finger [illegible]
DATE: [illegible]
SHEET: A-20
OF
REVISION

Finger Hogging & Sagging

Primary Stress: Mmax 615500 k-f

f_{top} = 615500/3078 = 199.6 ksf = 1386 psi (c)

f_{bot} = 615500/3078 = 199.6 ksf = 1386 psi (T)

Secondary Stress @ Bottom Slab

a) At bottom due to Buoyancy: longitudinal side span = 20'

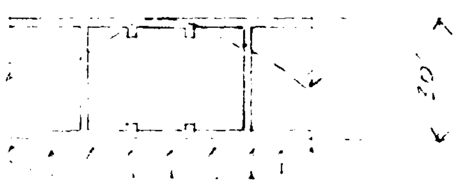
D.L.:

Concrete: 5/12 × .15 = 0.18 KSF

Mech + Misc = 0.05

Max. Buoyancy = .064 × 30' = 1.9

Resultant = 1.69 ksf



Assume max. water (Wave height = 20')

Finger Long. Section

Slab Section Properties:

At support: I = 0.28 ft⁴

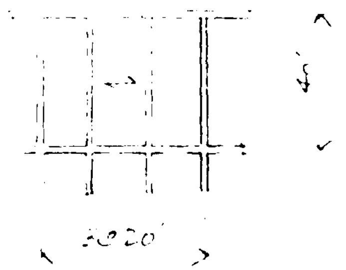
Haunched t = 15", S = 0.29 ft³

b) Moment: Ln 19', L2 = 40'

> 2.0

Mmax = wL²/11

= 1.69 × 19²/11 = 55 k-f



c) Stress: f = 55/0.29 × 1.33 = 101 ksf — See Plan

= 756 psi

— increase allowable by 33% as loading is temporary

Secondary Stress @ Top Slab

a) Loading

D.L. Concrete = 15/12 × .12 = .15 ksf

Mech + Misc = .10

Live Load: Allowable so that = .30 ksf

Freeboard same as Expedit[illegible] .55 ksf

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St. San Francisco, Ca 94133

PROJECT: Navy Pier
ITEM: Expeditionary Pier
DESIGN: Finger [illegible], Stresses
DATE: XII 82 KA1

SHEET A-21
OF
REVISION

Cont' Finger Pier Stresses @ Top Slab :

[illegible] Moment: $M = wl^2/11$

$= .55 \times 19^2/11 = 18^{K-F}$

[illegible] Section [illegible]: $I = [illegible]^{F4}$

[illegible] = 15 $S = 0.26^{F3}$

[illegible] Stresses : [illegible] 18 / .26 = 69 KSF

= 481 psi (±)

Combination of Stresses :

	Max Tension (psi)		Max Compression (psi)	
	Longitudinal	Transverse	Longitudinal	Transverse
[illegible]	1386	1386	1386	1386
[illegible]	481	—	756	—
Σ	1867	1386	2142	1386
Water Head		− 16	+ 106	+ 106
Total Max.	1867	1370	2248 ✓	1492 ✓

* [illegible] compression due to Water Head

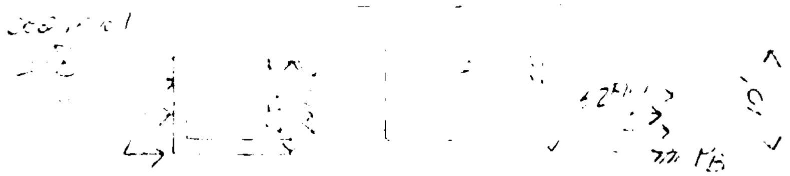
1) Still Water:

[illegible] Draft = 10'

Resultant : [illegible] × 10 × 10/2 = 3.2 K/l

Finger [illegible]

F_T



$F_T = 3.2 \times [illegible] / 30 = [illegible]5^K$

$F_B = [illegible].85^K$

Note: This reactions are high, since Exterior slab also spans horizontally

[illegible]:

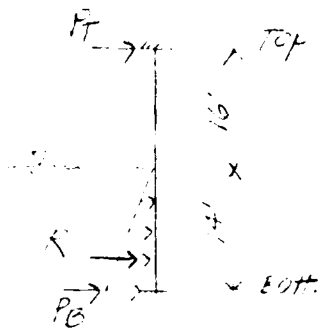
Top [illegible] = 450# / [illegible] = 1.9 psi ignore

Bottom [illegible] = 2350 / [illegible] = 16 psi

TY LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca 94133	PROJECT: Navy Pier ITEM: Expeditionary Pier DESIGN: Angel Casting DATE: XII 82 KM	SHEET A-22 OF REVISION

Cont' Water Head Stresses (still water)

3) Live load + Dead load, Draft = 14'
(Under 250 PSF live load)



Resultant = .064 × 14 × 14/2
= 6.3 K/l

AT 14/3 = 4.7' From bottom

Reactions:

P_T = 6.3 × 4.7 / 30' = 1.0 K/l
P_B = 5.3 K/l

Stresses due to Draft of Dead + Live:

f_T = 1000# / 15 × 12 = 5.5 psi (tensile)
f_{BOT} = 5300 / 15 × 12 = 29 psi

4) Wave Induced

Assume an wave height of 30'

Resultant = .064 × 30²/2 = 29 K/l
P_T = 29 × ... = 10 K
P_B = 29 × 2/3 = 19 K/l

Stresses: f_T = 10000 / 15 × 12 = .05 ksi
f_{BOT} = 19000 / 15 × 12 = .106 ksi

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St. San Francisco, Ca 94133

PROJECT	Navy Piers
ITEM	Expeditionary Pier
DESIGN	Final Prestressing
DATE	[illegible]

SHEET A-23 OF ____ REVISION

Longitudinal Prestressing:

[illegible] - Assume [illegible] [illegible] [illegible] [illegible] 85% [illegible] Tension Stress.

[illegible] 7000 [illegible] 150% [illegible] 282 sf

[illegible] 0.75 x 1550 psi / 1.07 [illegible] psi 282 sf → 7% increase

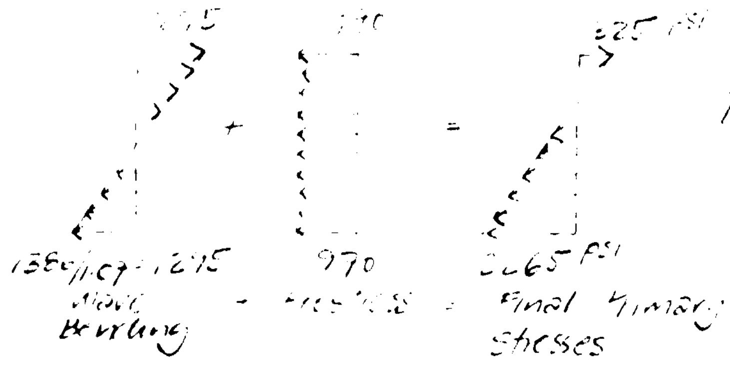
[illegible] .386 / 1.07 = 1295 psi

Residual Tension: 1295 - 970 = [illegible] ([illegible] steel)

[illegible] Compression

	Longitudinal	Transverse
[illegible]	970 + 275 = 2265	2362
[illegible]	750 + 106 = 862	106
Σ	3,127 psi	2438 psi

[illegible] → 7000 psi [illegible]



Total Postensioning:
$140^{KSF} \times 282^{SF} = 39390^{K}$

T.Y. LIN INTERNATIONAL
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315 Bay St., San Francisco, Ca 94133

PROJECT	Navy Piers
ITEM	Finger Pier
DESIGN	[illegible]
DATE	[illegible]
SHEET	A-24
OF	
REVISION	

Finger Pier Weights:

Dead Load:

$\bar{A} = 282 \times 1/3 + 263 \times 2/3 = 270^{SF}$

[illegible] = [illegible] [270 × 500 + [illegible]]
= [illegible] 441 k

[illegible] = .120 × [1.5 × 2 × [illegible]]
= [illegible] k

Σ = [illegible] k

Piping = 0.035 × 2 [illegible] × 4000 [illegible]
= 507 k

[illegible] = 0.100 × 4000 [illegible]
= [illegible]

Total [illegible] : 24639 k ←

[illegible] In order to keep freeboard [illegible] of finger pier [illegible] [illegible] for [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] in order to bring [illegible] [illegible] [illegible]
[illegible] [illegible] storage, [illegible], [illegible] tanks, weapons, etc.

Live Load (psf)	Total Live Load	Total Dead Load (k)	Σ (k)	Draft (ft)	Freeboard (ft)
0	0	24639	24639	9.6	20.6
100	4000	"	28639	11.0	19.0
200	8000	"	32639	12.6	17.4
300	12000	"	36639	14.2	15.8
400	16000	"	40639	15.7	14.3
500	20000	"	44639	17.3	12.7
600	24000		48639	18.8	11.2

T.Y. LIN INTERNATIONAL
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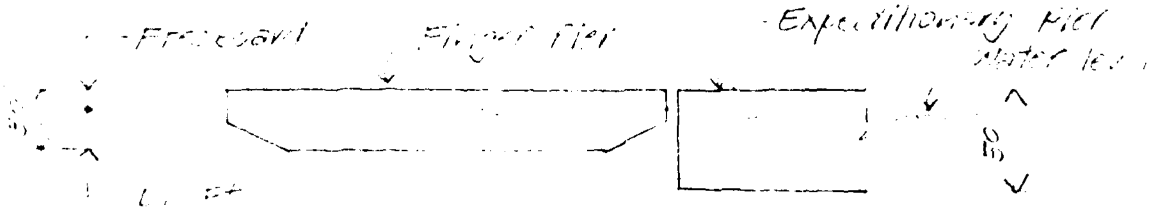
PROJECT: Navy Piers
ITEM: Expeditionary Pier
DESIGN: Draft and Freeboard
DATE: [illegible]

SHEET: A-25
OF
REVISION:

Draft and Freeboard

Expeditionary Pier Maximum Live Load Draft: 17.8'
Due to Live Load Average = 520 PSF
Total Bearing Area = 378400 #

Live Load Range (psf)	Total Live Load (k)	Total Dead Load (k)	Σ (k)	Draft (ft)	Freeboard (ft)
0	0	255600	255600	19.6	30.4
100	37840	"	293440	22.5	27.5
200	75680	"	331280	25.4	24.6
300	113520	"	369120	28.3	21.7
400	151360	"	406960	31.2	18.8
500	189200	"	444[illegible]	34.1	15.9



Light Ship and Full Load Freeboard Comparison:

Expeditionary Freeboard (Ft) Light Ship	Expeditionary Freeboard (Ft) Full Load	Finger Pier Freeboard (ft) Light Ship	Finger Pier Freeboard (ft) Full Load	Δ Freeboard (ft)
30.4	—	20.5	—	9.9 Exp.
	[illegible]	20.5	—	12.0 Fing.
30.4	—	—	11.2	19.2 Exp.
—	[illegible]	—	11.2	1.8 Exp.

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PROJECT:	Navy Pier
ITEM:	Expeditionary Pier
DESIGN:	Draft and Freeboard
DATE:	X'82 KM

SHEET: A-26
OF
REVISION:

Cont' Freeboard Comparison:

Summary:

- in order to maintain same freeboard between Finger and Expeditionary piers, either one of the piers must be ballasted. Assuming that during service the equivalent most common live load in the E.P. is 400 PSF, then the equivalent uniform load in the Finger pier must be around 320 PSF in order to maintain same freeboard of 18.3 Ft.
- the minimum average superimposed load in the Expeditionary Pier should be around 320 PSF so that the maximum freeboard allowed of 20.5 Ft. is not exceeded.
- Since the freeboards of the pier structures will most likely be different due to the action of waves, wind and current it is necessary to joint the piers with either a hinge, free of rotation or chain like type of connection.
- To keep freeboard differences to a minimum there should be a system in each pier that monitors freeboards and ballasts each pier in order to level the decks of both structures.

T.Y. LIN INTERNATIONAL
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315 Bay St., San Francisco, Ca 94133

PROJECT	Navy Piers
ITEM	Expeditionary Pier
DESIGN	Finger Periods
DATE	[illegible] KM

SHEET A-27
OF
REVISION

Roll Period :

Draft :

Dead load draft : $\frac{24639^k}{.064 \times 80 \times 500'} = 9.6'$

Live load draft :

@ 150^{psf} = $\frac{6000}{.064 \times 80 \times 500} = 2.34'$

Σ (DL + LL) = 11.9'

Vertical center of Gravity @ under dead + live loads

$H = \frac{24639^k \times 15' + 6000^k \times 30'}{30639^k} = 17.9'$ (From bottom)

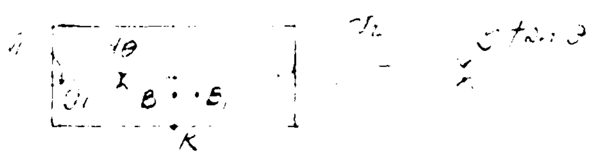
Center of buoyancy

$\overline{KB} = 17.9'/2 = 9'$ from base line.

Block coefficient at Draft 11.9

$C_b = 35\Delta / L \times B \times d = 30639 / (40000 \times 11.9 \times 2.24/35)$
$= 1.0$

Transverse Metacentric Height



$\overline{BM} = \frac{\overline{BB_1}}{\tan d\phi} = \frac{v \times \overline{g_1 g_2}}{\nabla \tan d\phi}$

for a small angle ϕ

$v = [illegible]$ $2y = 80'$

$\nabla = \overline{LxB} \times d \times C_b = 40000 \times 11.9 \times [illegible] = [illegible] \times 10^3 F^3$

$\overline{g_1 g_2} = 4/3\, y = 53'$

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PROJECT: Navy Piers
ITEM: Expeditionary Pier
DESIGN: Finger Pier Periods
DATE: 1982 KM
SHEET: A-28
OF
REVISION:

Con't Finger Periods:

$\overline{KM} = \overline{KB} + \overline{BM}$

$\overline{KB} = 9'$ From Base

$\overline{GM} = \overline{KM} - \overline{KG}$

$\overline{KG} = H = 17.9'$ From Base

For $\phi = 10^\circ$

$v = \frac{1}{2}\ 40^2 \tan 10^\circ \times 500'$

$= 70531\ F^3$

$\overline{BM} = \dfrac{70531 \times 53}{476 \times 10^3 \times \tan 10^\circ} = 44.5'$

$\overline{KM} = 9 + 44.5 = 53.5'$

$\overline{GM} = 53.5 - 17.9 = 35.6'$

Roll Period: $T_\phi = \dfrac{C\overline{E}}{\sqrt{\overline{GM}}}$ $C = 0.52$ (Pontoon) $\overline{E} = 80'$

$T_\phi = \dfrac{0.52 \times 80}{\sqrt{35.6}} = 6.7$ sec ←

Pitch Period:

$\overline{BM_L} = \dfrac{v \times \overline{g_1 g_2}}{V \tan \phi}$

For $\phi = 10^\circ$

$v = \frac{1}{2}\left(\frac{500}{2}\right)^2 \tan 10^\circ \times 80 = 440.8 \times 10^3$ ...

$V = 40000 \times 119 \times 10 = 476 \times 10^3\ F^3$

$\overline{g_1 g_2} = \frac{4}{3}(500/2) = 333'$

$\overline{BM_L} = \dfrac{440800 \times 333}{476000 \times \tan 10^\circ} = 1749'$

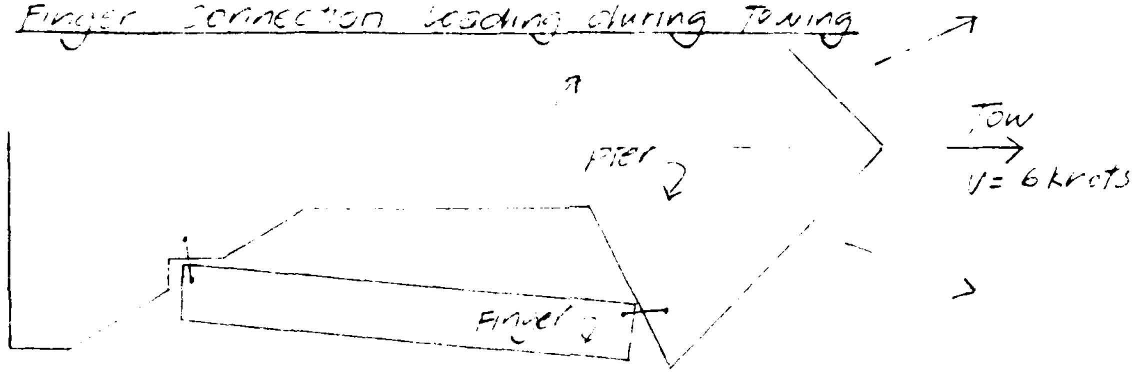
$\overline{KM} = 9 + 1749 = 1758'$

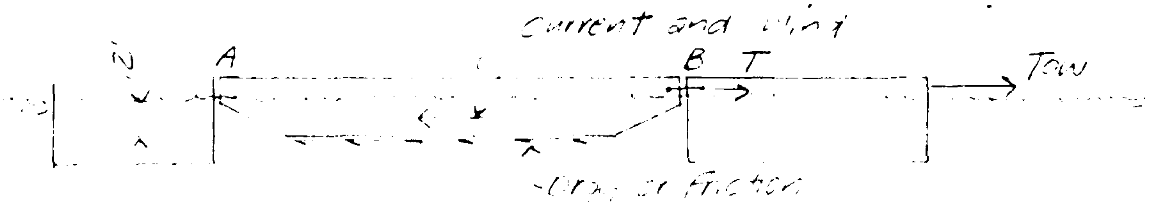
$\overline{GM} = 1758 - 17.9 = 1740'$

Pitch $= \dfrac{0.52 \times 500'}{\sqrt{1740}} = 6.2$ sec ←

T.Y. LIN INTERNATIONAL — STRUCTURAL ENGINEERING, 315 Bay St., San Francisco, Ca 94133	PROJECT: Navy Piers	SHEET: A-29
	ITEM: Expeditionary Pier	OF
	DESIGN: Hinge Connection Loading	REVISION:
	DATE: [illegible] 82	

Finger Connection Loading during Towing





Forces caused by Resistance of Finger to motion must be taken by Connections @ A and B

Resistance Forces: $R = \Sigma R_F + R_r + R_{air}$

a) Frictional Resistance R_F (Frictional Resistance)

$R_F = f S V^{1.825}$

f = Frictional constant (from Table 4, Chp. [illegible], Naval Architects, [illegible])
= 0.0098

S = wetted surface area (sq. ft)
= [illegible] — L = length
S = [illegible] + [illegible] — d = draught = 12' (under 120 psf live load)
= 50200 ft² — V = Volume of displacement (ft³) = 12' × 500' × 85' = 480000 ft³

V = Velocity of Ship
= 6 knots

R_F = [illegible] × 50200 × 6^1.825
= [illegible]

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Finger Resistance to Motion (cont')

b) Wave Making + Eddy Resistance: R_r

From Fig. 15 Naval Architects [illegible]

$V = 6$ knots $L = 500'$

Interpolate to find $R_r \approx 3^k$

c) Air Resistance : $V_{air} = 40$ mph

$R_{air} = C_{yw} \times \frac{1}{2} \times P_w V^2 A_s$

Wind @ 90° to longitudinal axis

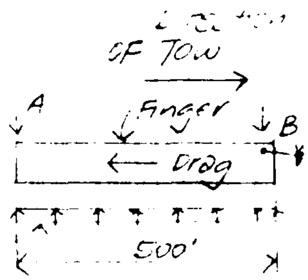
$V_{air} = 40$ mph $\times$ 5280/mile / 3600 $= 59$ ft/sec

$C_{yw} = 1.0$

$P_w = 0.00237$ #-sec²/ft⁴ @ 68°F

$R_{air} = 1.0 \times \frac{1}{2} \times 0.00237 \times 59^2 \times 500' \times 18'$

$= 37^k$



d) Current Resistance : $V = 4$ knots @ 90° to long. axis

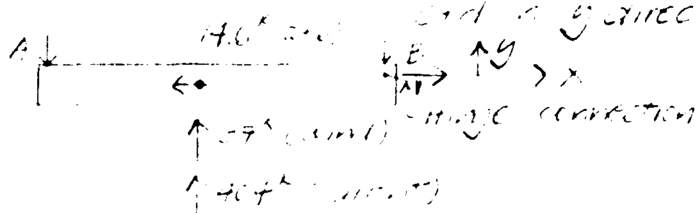
Assume that the current acts w/ 40 mph wind during towing

$R_c = KA_s V^2$ $K = 1.5$

$= 1.5 \times 6000 \times 6.7^2$ $A = 500' \times 12' = 6000$ ft²

$= 404^k$ $V = 6.7$ F/S

Free-Body
Load Combination II : [illegible] in x direction
wind in y direction > compare to Load Case I



Reactions @ B : $\Sigma F_y = 0$ ∴ $B_y = (37 + 404)/2 = 221^k$

$\Sigma F_x = 0$ ∴ $B_x = 14.6^k$

Tension @ B $= (221^2 + 14.6^2)^{1/2} = 222^k$ << 5280^k

TYLIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca 94133

PROJECT:	Navy Pier
ITEM:	Expeditionary Pier
DESIGN:	Hinge Connection Loads
DATE:	[illegible]

SHEET: A-31
OF
REVISION:

Appendix : Environmental Load Calculations:

Finger Pier Loading:

[illegible] Wind [illegible]

[illegible] $V^2 A_s$

[illegible]

[illegible] $\frac{\#-sec^2}{ft^4}$ [illegible] F

[illegible] Pier @ 30' [illegible]

Hurricane Velocity, V = 90 mph = 132 '/sec

A_s = [illegible] Projected Area

[illegible] = 470' × 8' × 30'

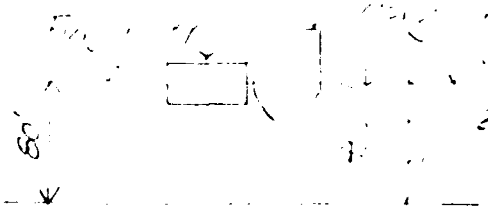
L = 470' h = 30' A_s = 3800 [illegible]

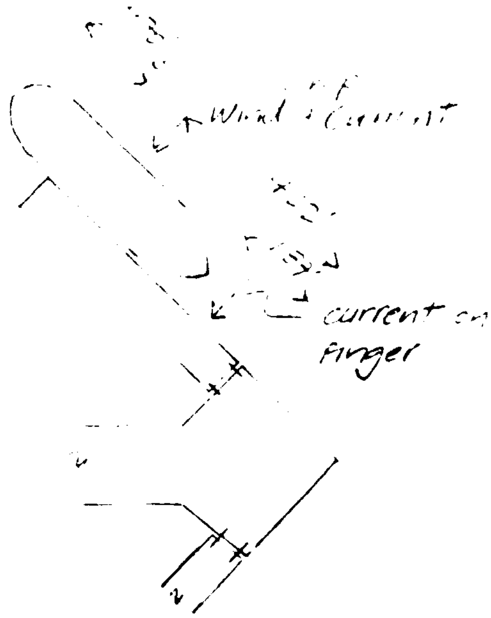
[illegible] ($\ldots)^2$ (3800)

= [illegible]

[illegible] Current [illegible]

[illegible]





[illegible] L = 470'
Draft = 25

TY-LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca 94133	PROJECT Navy Piers ITEM Expeditionary Pier DESIGN Hinge Connection Loading DATE [illegible]	SHEET A-32 OF REVISION

[illegible] for Transverse Current [illegible]:

Determine current forces by:

1. Approximate Method only

For Future Navy Pier 470' x 80' x 35'

Approximate Method:

$F_C = K A_p V_C^2$ $\quad K = .5$ for [illegible] cylinders ←

$F_C = [illegible] (5.9)^2$ $\quad A_p = 470 \cdot [illegible]$

$F_C = 573$ [illegible] $\quad V_C =$ avg. current velocity $= 5.9$ ft/s

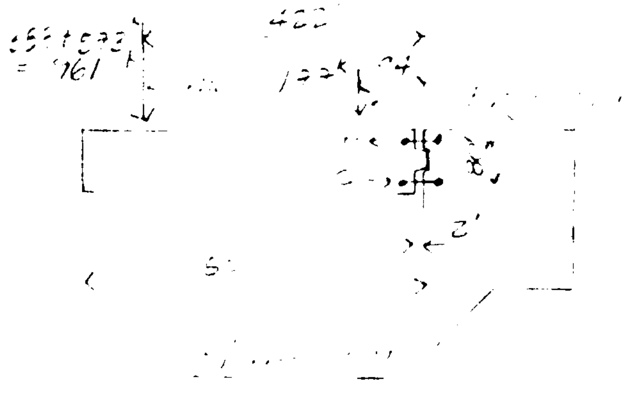
[illegible]

$F_{[illegible]} = [illegible]$ $\quad K = .5, \; A_p = 12' \cdot 187' = 2244$

$= .5(2244)(5.9)^2$ $\quad V_C = 5.9$ ft/s

$= 17^k$

Worst [illegible] [illegible] wind + current:



[illegible] Assumptions:

1. IF hinged [illegible]

- Take tension and compression couple in link [illegible] between [illegible] piers.

No energy is dissipated into water (no drag). All load goes to connections

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PROJECT	Navy P.I.
ITEM	Expedient Pier
DESIGN	Finger/Spine Pier Conn.
DATE	XII 82 RM
SHEET	A-33
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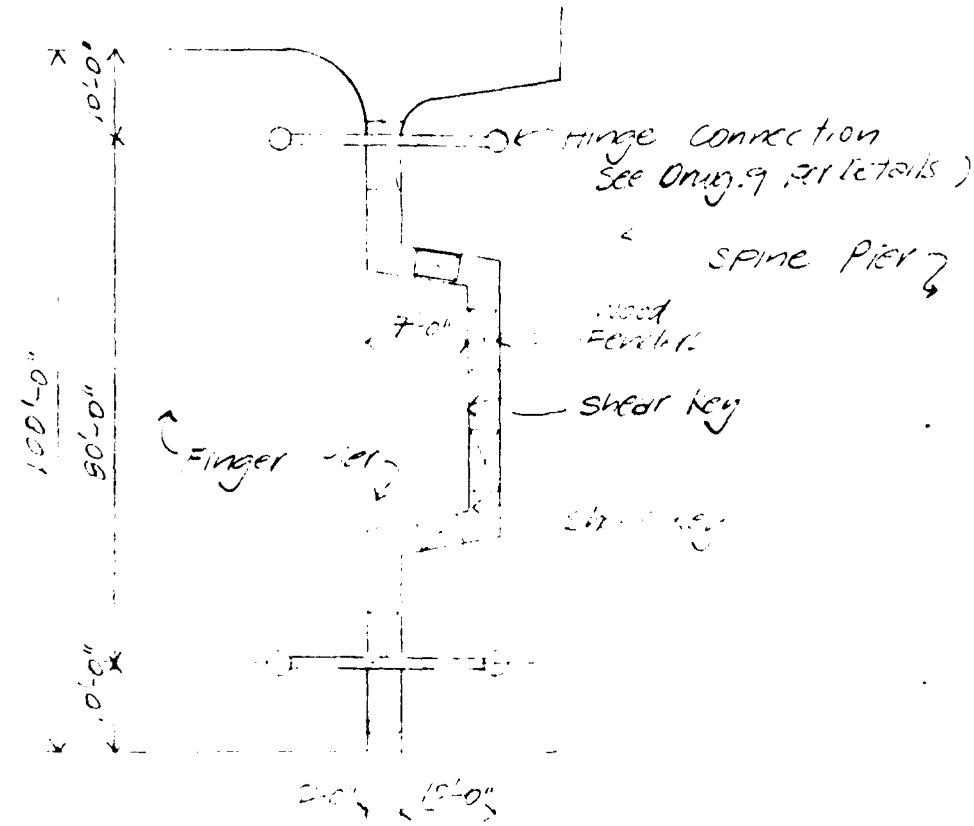
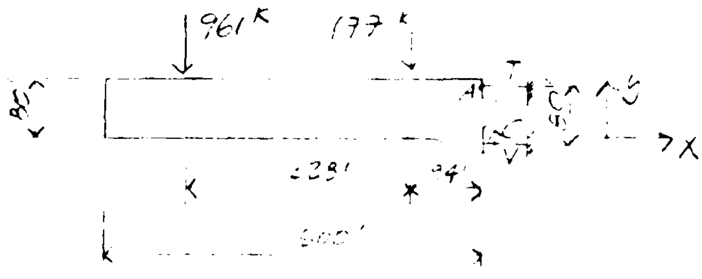


Load Combination I : wind + current @ service conditions governs

Free Body Diagram



$\Sigma F_y = 0$

$V = 961 + 177$
$= 1138^k$ (into shear key)

$\Sigma M_A = 0$

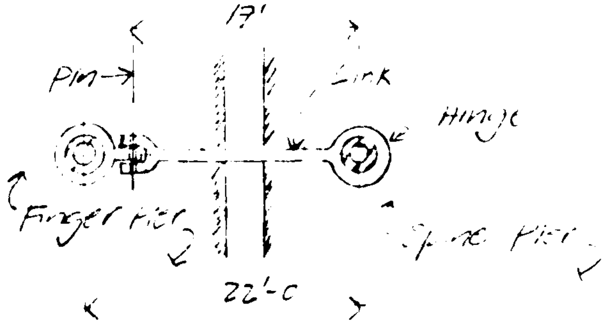
$C = T = \frac{(961^k \times 422' + 177^k \times 94')}{80'}$
$= 5277^k$

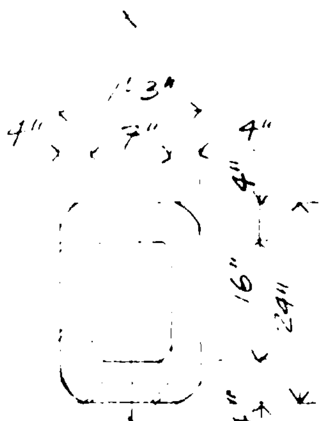
Design of Connection

Link Design :

Compression Load: 5280^k ←——— governs

Cont' Link Design





Link Section

Hinge Connection Plan

Use Fy = 50 ksi steel

Rectangular Box Section

Areq. Tension = 5280 / 0.6x50 = 176 in²

Try A = 248 in² (see section above)

$I_{xx} = 24 \times 15^3 / 12 - 16 \times 7^3 / 12 = 6292$ in⁴

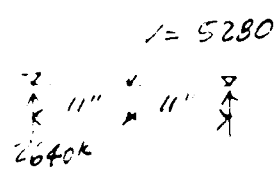
$r_y = \sqrt{6292 / 248} = 5''$

$KL/r_y = 1.0 \times 17 \times 12 / 5 = 40 < 300$ satisfy tension requir

Fa allowable = 26 ksi in compression

Areq = 5280ᵏ / 26 ksi = 203 in² < 248 in² ok

Pin Design



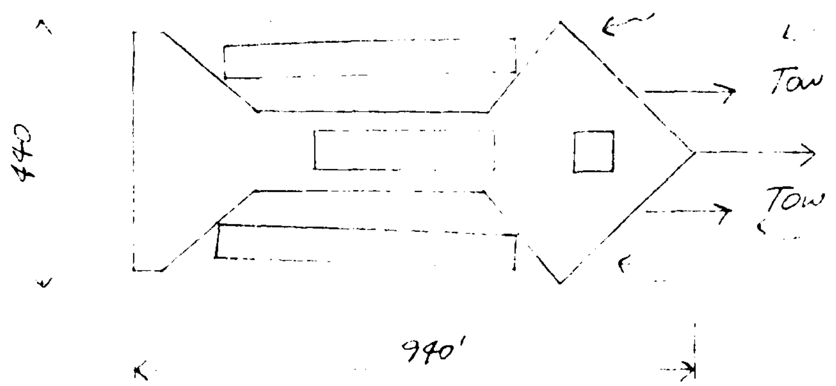
Reaction = 5280/2 = 2640ᵏ

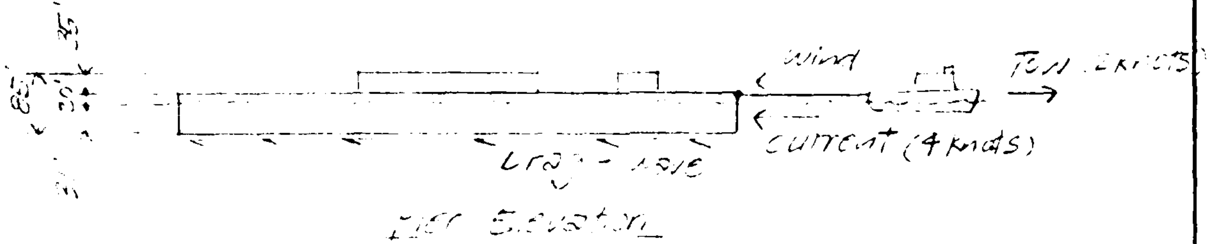
Fy = 50 ksi (pin)

Areq = 2640 / 50x0.4 = 132 in²

Use 16" φ Pin, Aprov = 200 in²

Total Resistance to Movement :





Environmental loads

Current : 4 knots
Wind : 40 mph
Velocity : 6 knots max.

Total Resistance : R = Rf + Rr + Rw + Rc

(Rf: Drag; Rr: Wave making + Eddy; Rw: wind; Rc: current)

1) Friction Resistance — Max. drag will occur when pier is towed at a speed of 6 knots without any current or when a 4 knot current plus a towing speed of 4 knots occur.

Max drag at 4 knot speed and 4 knots current see current resistance

Reynold's Number = $\frac{VD\gamma}{\mu}$ = $\frac{7.7 \times 3.28 \times 440 \times 3.28 \times 992}{6.0 \times 10^{-4}}$ = 39×10^{8} $> 10^{4}$

T.Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca 94133	PROJECT: Navy Piers ITEM: Expeditionary Pier DESIGN: Resistance and Power DATE: [illegible] 83 RM	SHEET: A-36 OF REVISION:

Cont' Resistance to Movement

b) Extrapolate from Fig 35, Naval Architecture by Baxter

$L = 940'$

$V = 6$ knots

$R_{r_{EP}} \approx 10$ Tons $= 20^k$

R_r Total $= R_{r_{EP}} + R_{r_{FF}}$

$= 20 + 2\times3$

$= 26^k$ ← — ΣR_r

c) $R_w = C_{yw} \frac{1}{2} \rho_w V_w^2 A_s$

$V_{air} = 40$ mph $= 59$ F/s

$C_{yw} = 1.0$

$\rho_w = 0.00237$ #-sec²/ft⁴ @ 63°F

$A_s = 440' \times 31' + 120' \times 35'$

$= 17840$ ⌀

$R_{w_{E.P.}} = 1.0 \times \frac{1}{2} \times 0.00237 \times 59^2 \times 17840^{⌀} = 74^k$

R_w Total $= R_{w_{E.P.}} + R_{w_{FF}}$

$= 74 + 0$

$= 74^k$ ← — ΣR_w

d) Current Resistance : Use 6 knots (relative velocity)

$R_{c_{E.P.}} = R_{drag} = C_D A_p \rho \frac{V_c^2}{2}$

$= 1.2 \times 21080 \times 1.99 \times \frac{7.7^2}{2}$

$= 1490^k$

$A_p = 440' \times 31' + 240' \times 31'$

$= 21080$ ⌀

$V_c = 7.7$ F/s

$C_D = 1.2$ (Rectangle)

R_c Total $= R_{c_{E.P.}} + R_{c_{F.P.}}$

$= 1490^k$ ← — ΣR_c

Total Resistance $= 26^k + 74^k + 1490^k$

$= 1590^k$ ← — ΣR_T

Effective Horse-Power Required

$E.H.P. = \frac{R_T \times V \times 1.69}{550}$ $V = 6$ knots

$= \frac{1590,000 \times 6 \times 1.69}{550} = 29293 \times 1.2$ (Factor) $= 35152$ Ehp.

Use 3-12000 H.P. Tug boats ← — # Tug boats req'd

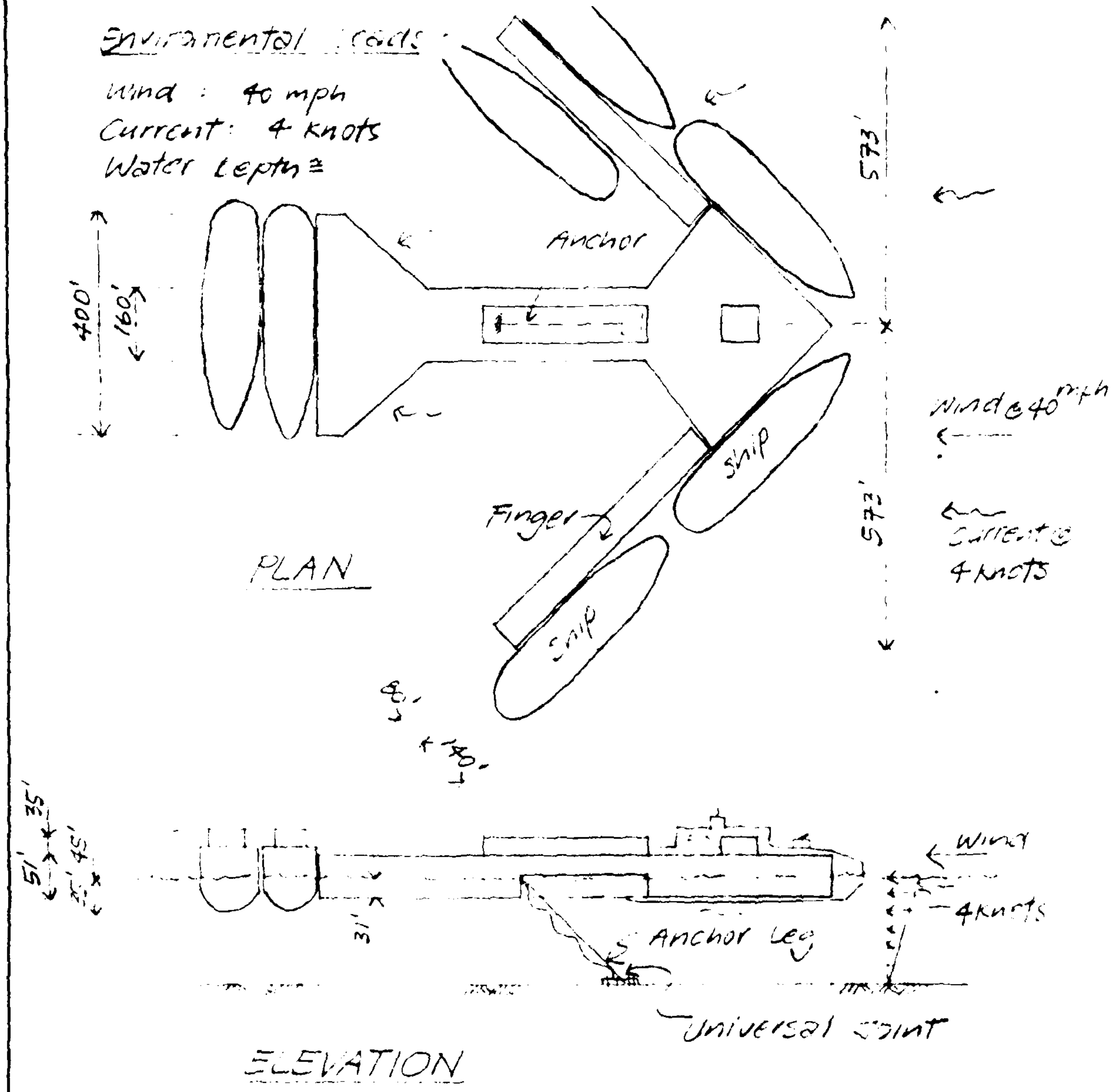
or 2-18000 H.P. Tug boat

T.Y. LIN INTERNATIONAL
STRUCTURAL ENGINEERING
315 Bay St., San Francisco, Ca 94133

PROJECT:	Navy Piers
ITEM:	Expeditionary Pier
DESIGN:	Anchor Leg
DATE:	1/1/82 KM
SHEET:	A-37
OF	
REVISION:	

Environmental Loads:

Wind: 40 mph
Current: 4 knots
Water Depth ≅



Expeditionary Pier draft = 31' (400 PSF Uniform Live Load)
Future Navy Ship = 470' × 40' × 30'
draft assume 35'
Assume 3 Ships nested @ one time when current (4 knots) and wind (40 mph)

T.Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco Ca 94133	PROJECT: Navy Piers
	ITEM: Expeditionary Pier
	DESIGN: Anchor Leg Loading
	DATE: XII 82 KM
	SHEET: A-38 OF ___ REVISION:

Wind Load :

$F_W = C_{yw} \cdot \frac{1}{2} \cdot \rho_w V_w^2 A_s$

$C_{yw} = 1.0$ wind @ 90°

$\rho_w = 0.00237 \frac{lb\text{-}sec^2}{F^4}$ @ 68°F

$V_w = 40$ mph $= 59$ F/s

A_s total $= A_s$ ships $+ A_s$ pier

$= 6 \times 470' \times 45' \cos 45° + 470' \times 45' + 17340^{\#}$ From previous calcs

$= 128722^{\#}$

$F_W = 1.0 \times 1/2 \times 0.00237 \times 59^2 \times 128722^{\#}$

$= 531^K$

Current Load :

Approximate Method :

$F_c = K A_c V_c^2$

$K = 2$ avg.

A_s total $= A_s$ ships $+ A_s$ pier

$= 6 \times 470' \times 35' \times \cos 45°$

$+ 470' \times 35' + 440' \times 31' + 240' \times 31$

$= 107321^{\#}$

$V_c = 4$ knots $= 5.1$ F/s

$= 1.2 \times 107321 \times 5.1^2$

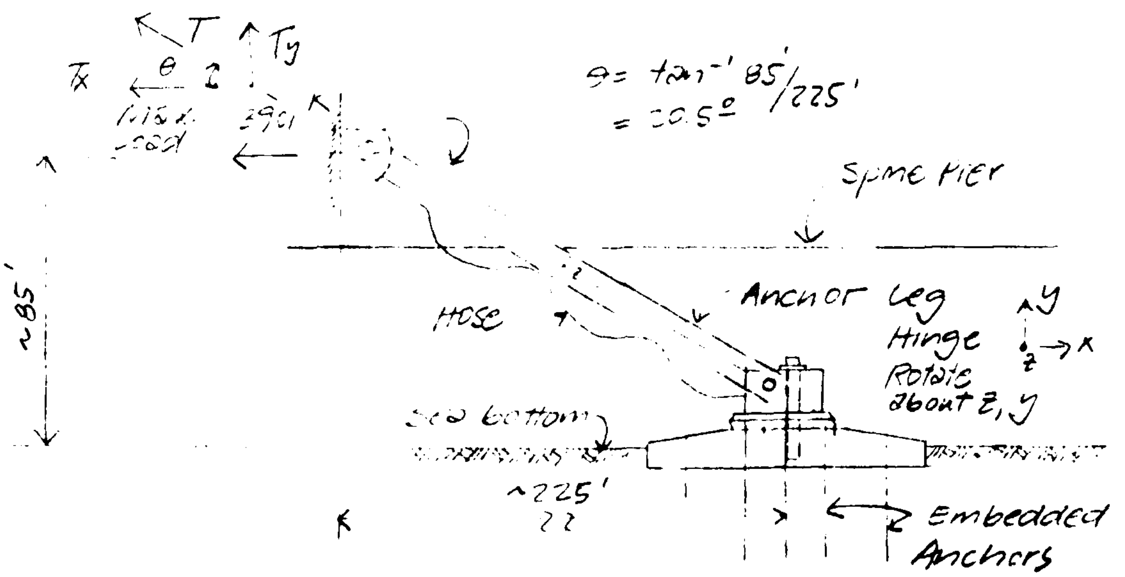
$= 3370^K$

Total Load $= 531 + 3370$

$= 3901^K$

$\theta = \tan^{-1} 85'/225'$

$= 20.5°$



T.Y. LIN INTERNATIONAL STRUCTURAL ENGINEERING 315 Bay St., San Francisco, Ca 94133	PROJECT: Navy Piers	SHEET: A-39
	ITEM: Expeditionary Pier	OF
	DESIGN: Anchor Leg Design	REVISION:
	DATE: XI/82 RM	

Cont' Anchor leg Loading:

$T_y = T_x \tan\theta$
$= 3901 \times \tan 20.6°$
$= 1474^k$

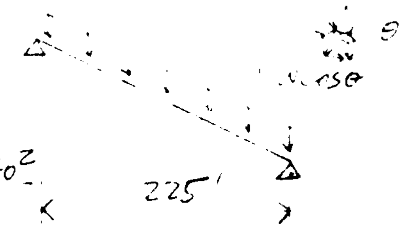
$T = \sqrt{T_x^2 + T_y^2} = \sqrt{3901^2 + 1474^2}$
4170^k

Leg Design $F_y = 50^{ksi}$

a) Tension: $A_{req} = 4170/50 \times 0.6$
$= 139^{in^2}$
Use avg. $A = 200^{in^2}$

b) Bending:

Dun weight: $\frac{200}{144} \times .49$
$= 0.68^{k/'}$

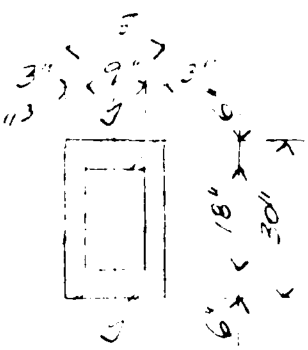


$M_{max} = \frac{wL^2}{8} = \frac{0.68 \times \cos 20° \times 240^2}{8}$
$= 4601^{k-f}$

$S_{x-x\ req} = 4601 \times 12 / 50 \times 0.66$
$= 1672^{in^3}$

$S_{prov\ x-x} = \frac{15 \times 30^3 - 9 \times 18^3}{6 \times 30} = 1900^{in^3} > 1672^{in^3}$
OK.

$A_{prov} = 288^{in^2} > 139^{in^2}$ req. ✓



Leg X-Section @ Midspan

Pin Design:

Shear $V = 4601/2 = 2300^k$
$A_{req} = 2300/50 \times 0.4 = 115^{in^2}$
Use 15"φ Pin

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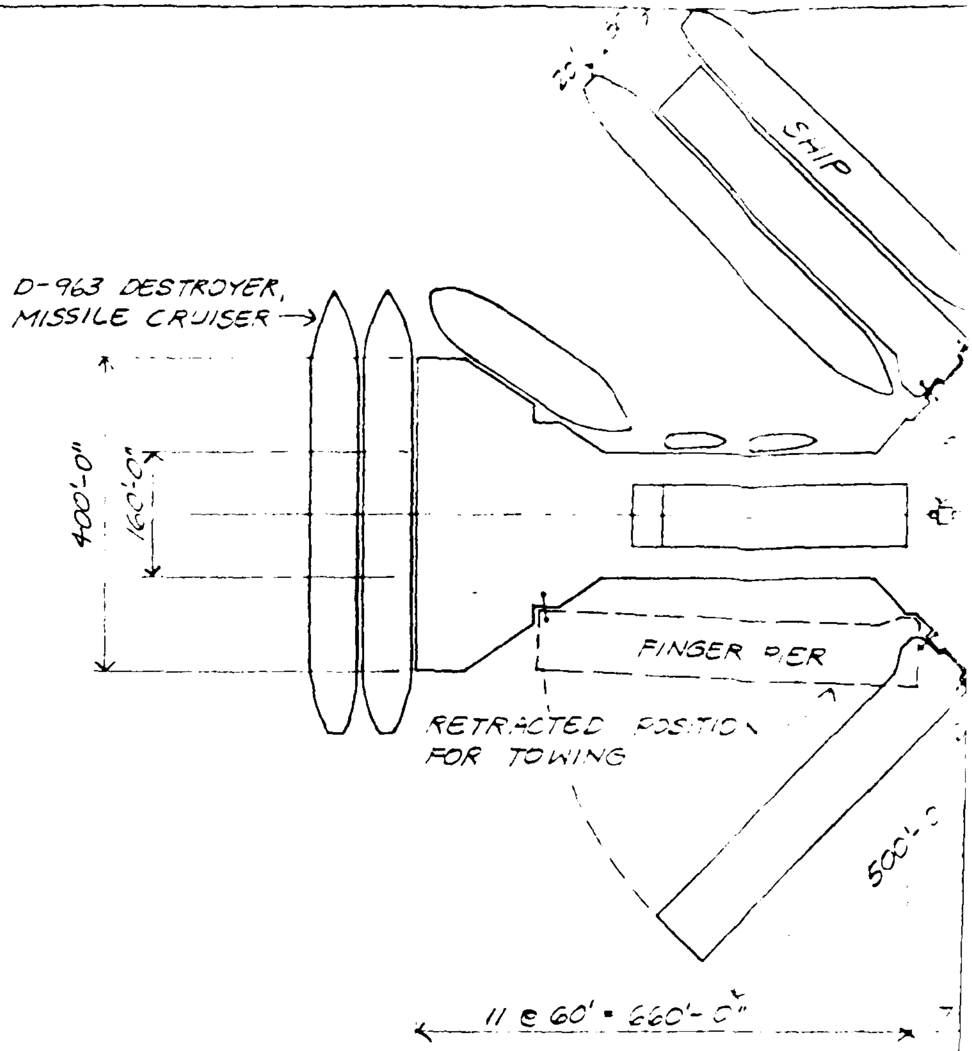
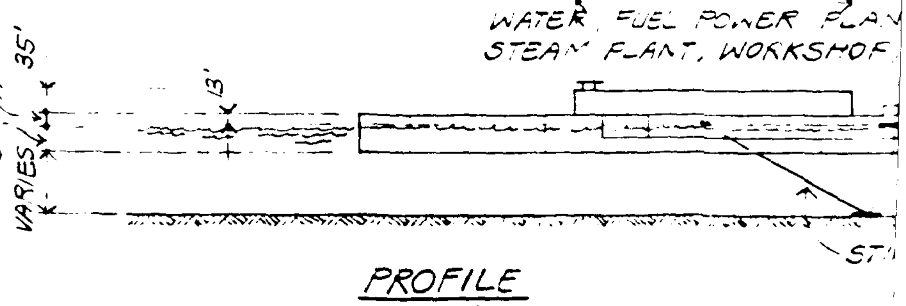


PLAN
1"=200'-0'



PROFILE
1"=200'-0"

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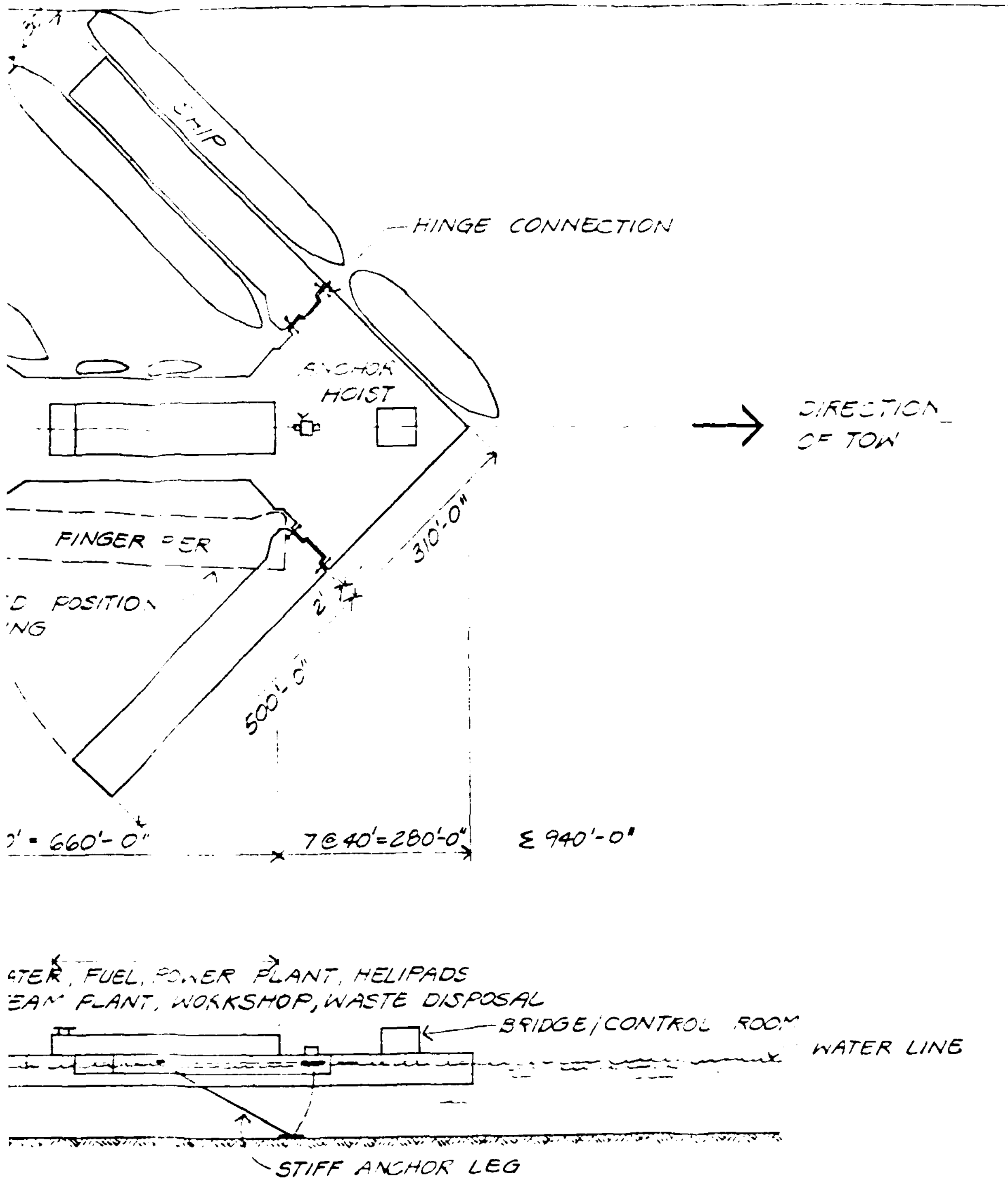

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SHEET TITLE: SCHEME A

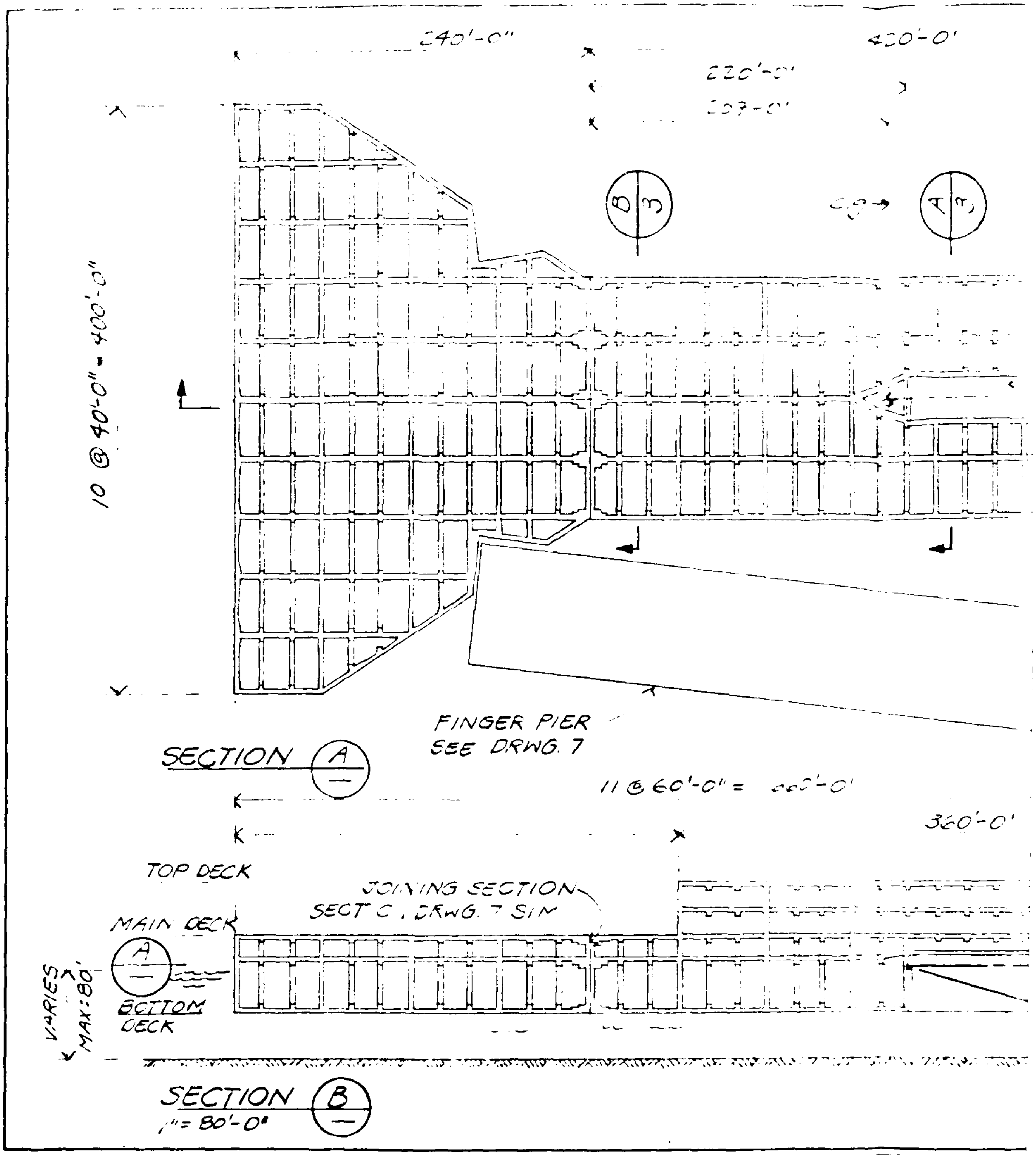
PROJECT: EXPEDITIONARY PIER

SHEET Nº 1

DRAFTING

DESIGN

PROJECT Nº



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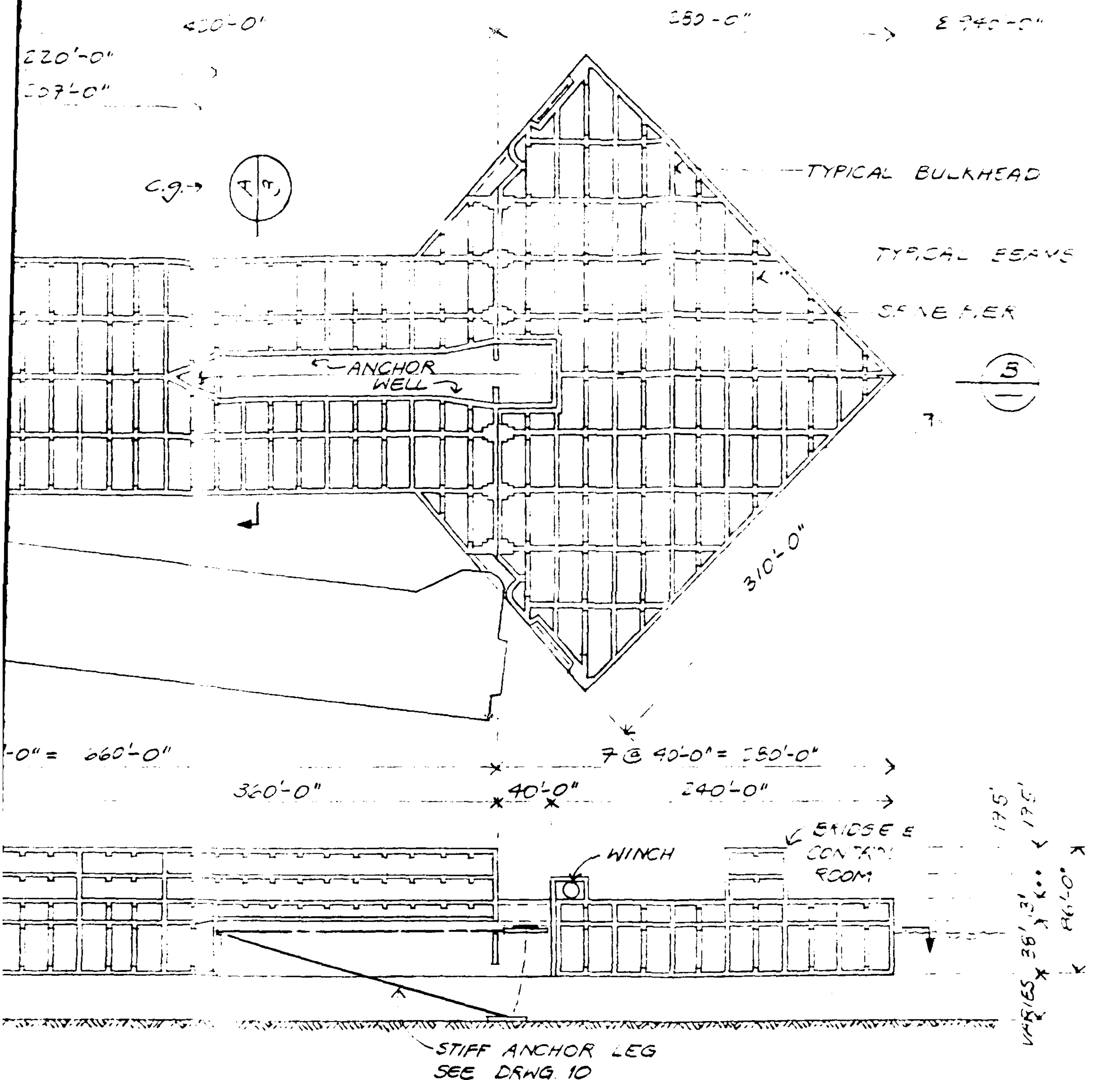

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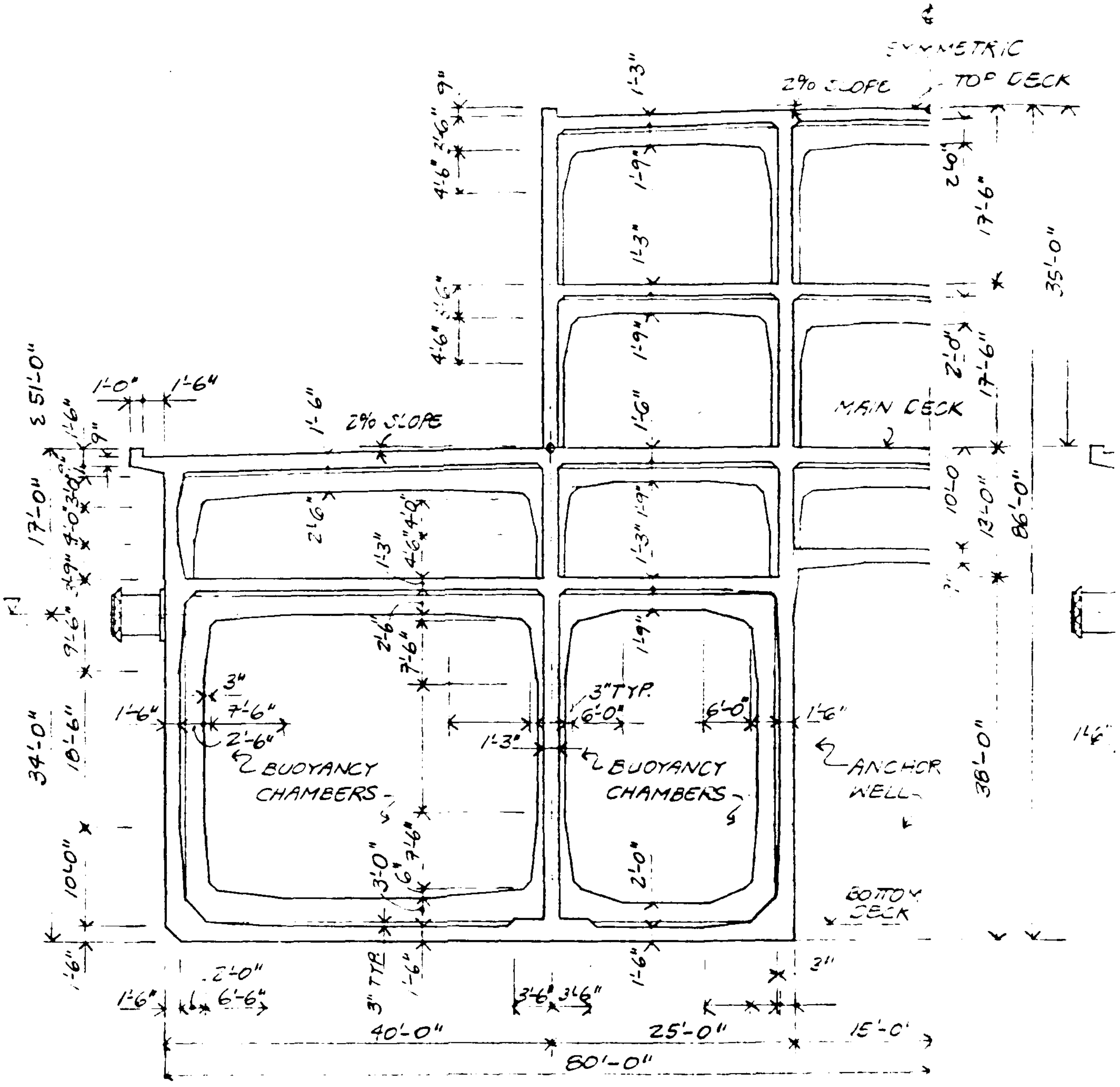
SHEET TITLE: SPINE LONGITUDINAL SECTIONS - SCHEME A

PROJECT: EXPEDITIONARY PIER

SHEET Nº: 2



SECTION A/2
3/4" = 1'-0"

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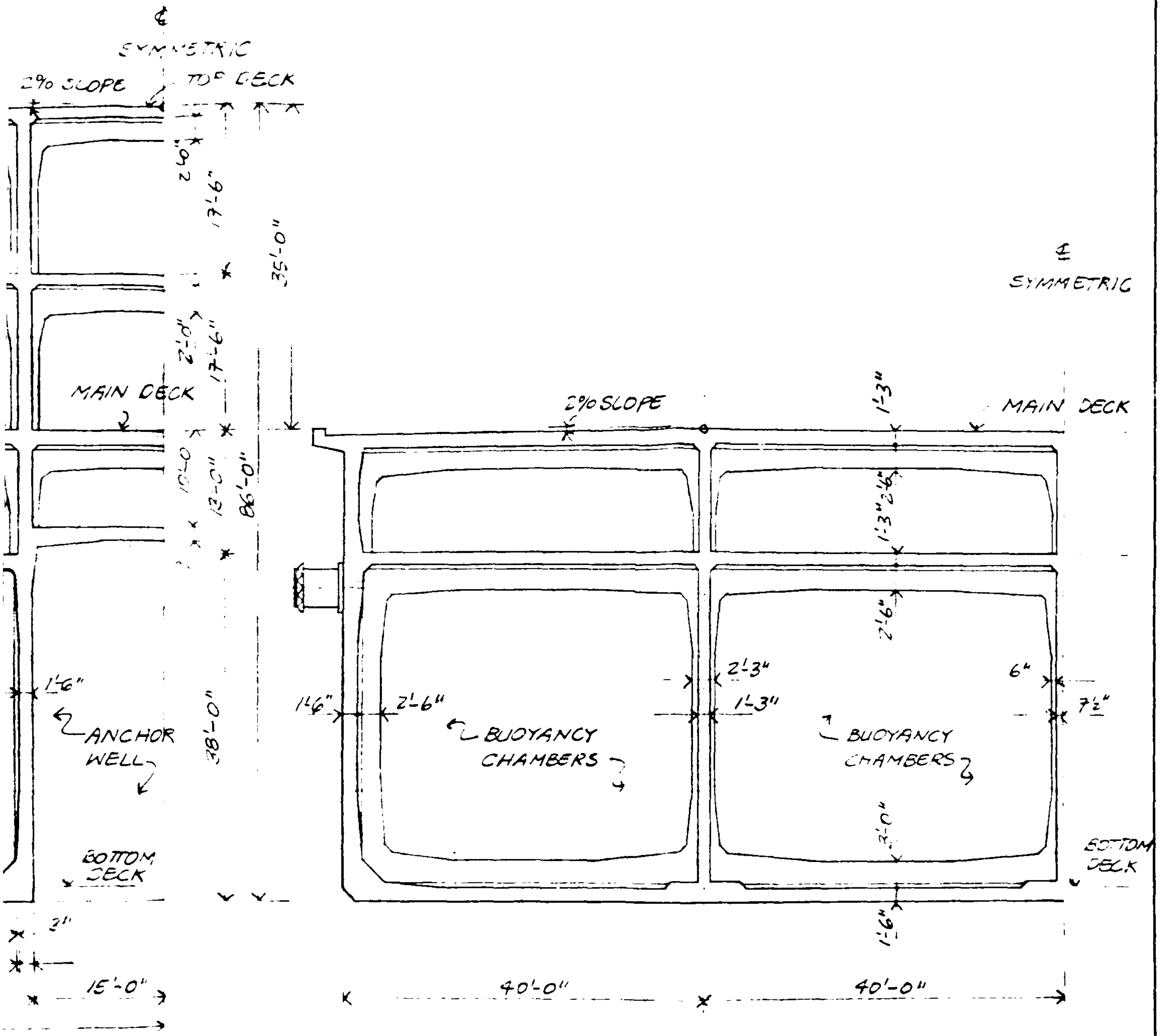

SECTION B/2
¾" = 1'-0"

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SHEET TITLE	SPINE PIER CROSS SECTION - SCHEME A
PROJECT	EXPEDITIONARY PIER
SHEET Nº	3

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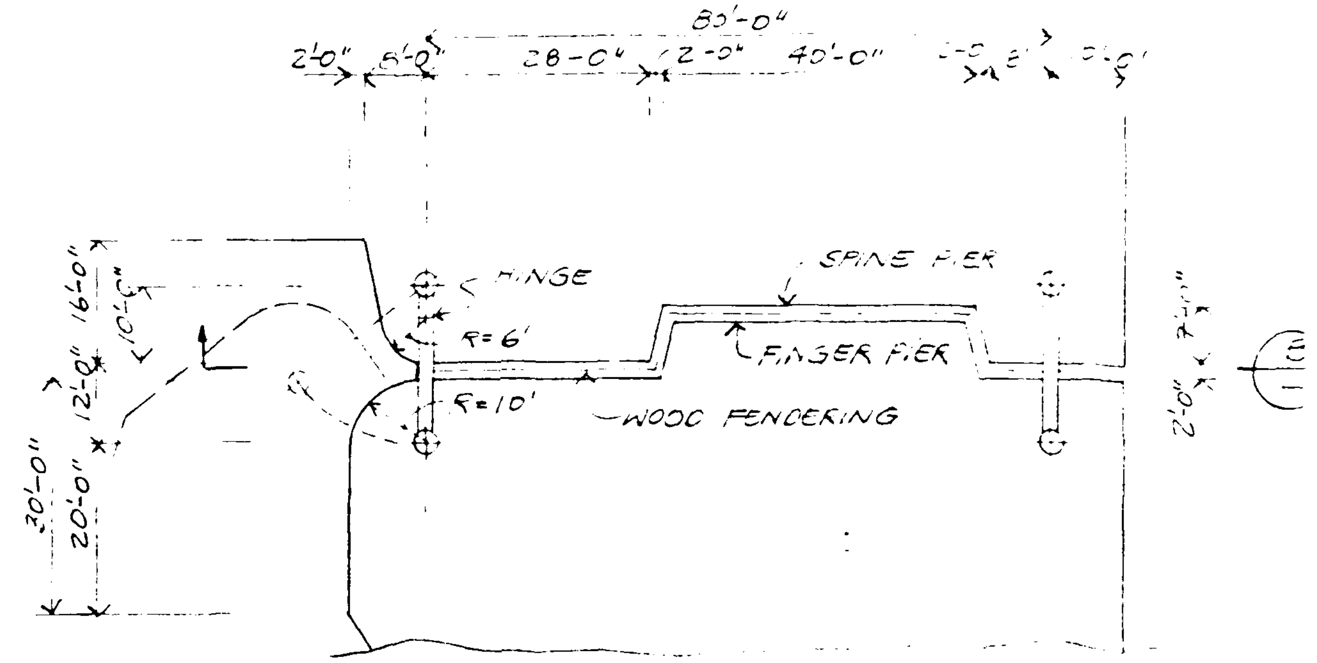
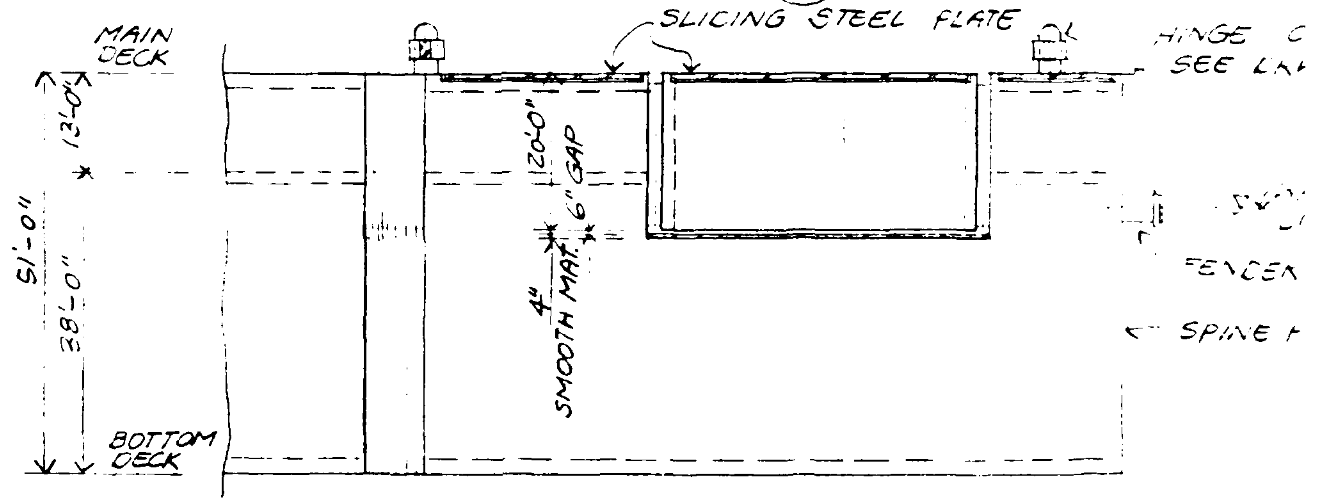
PROJECT Nº



DETAIL (A/2)



SECTION (B)

1" = 20'-0"

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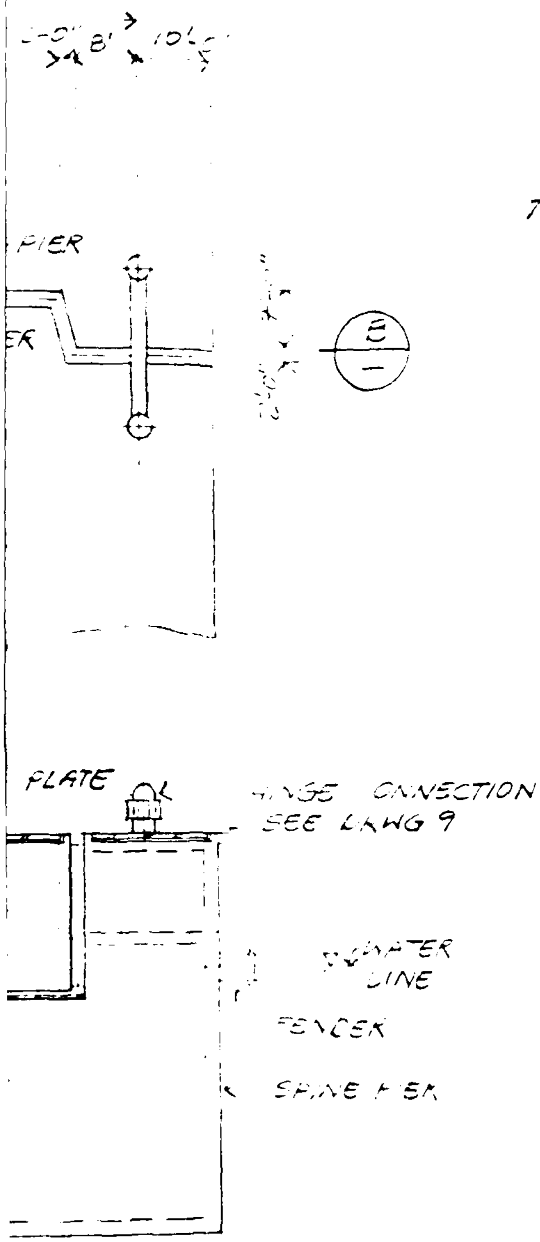
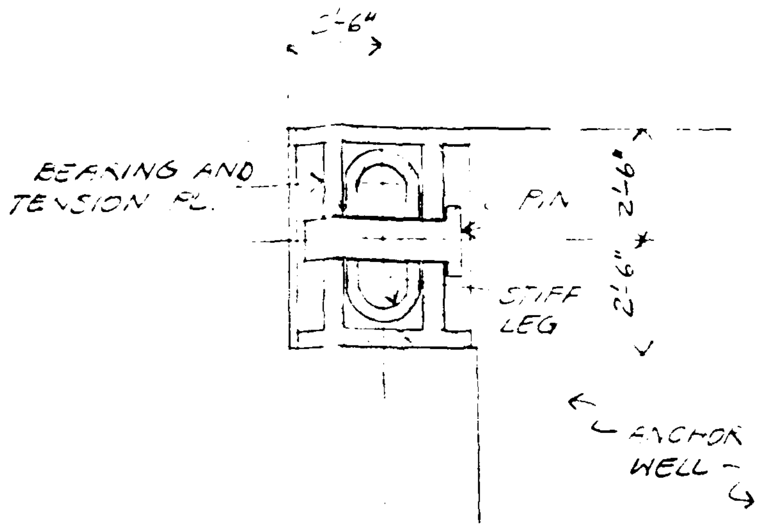
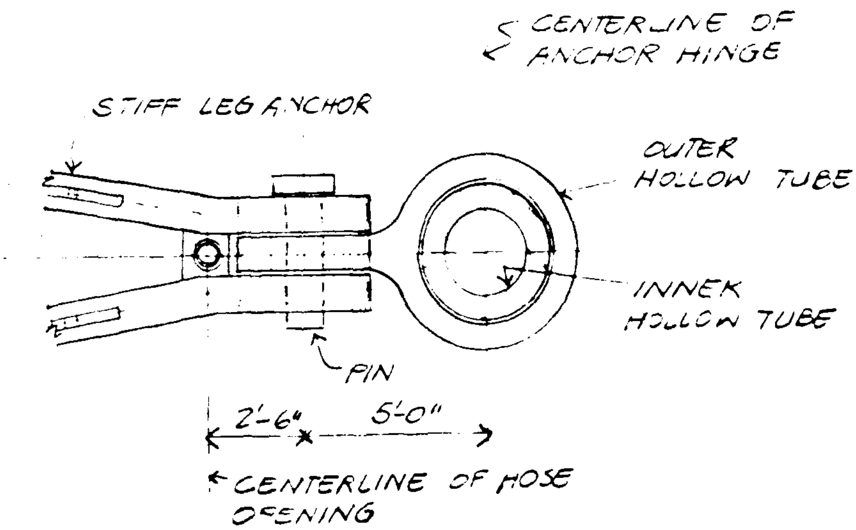




SECTION C/10



SECTION D/10
1/4" = 1'-0"

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SHEET TITLE: SPINE PIER DETAILS

PROJECT: EXPEDITIONARY PIER

SHEET Nº 4

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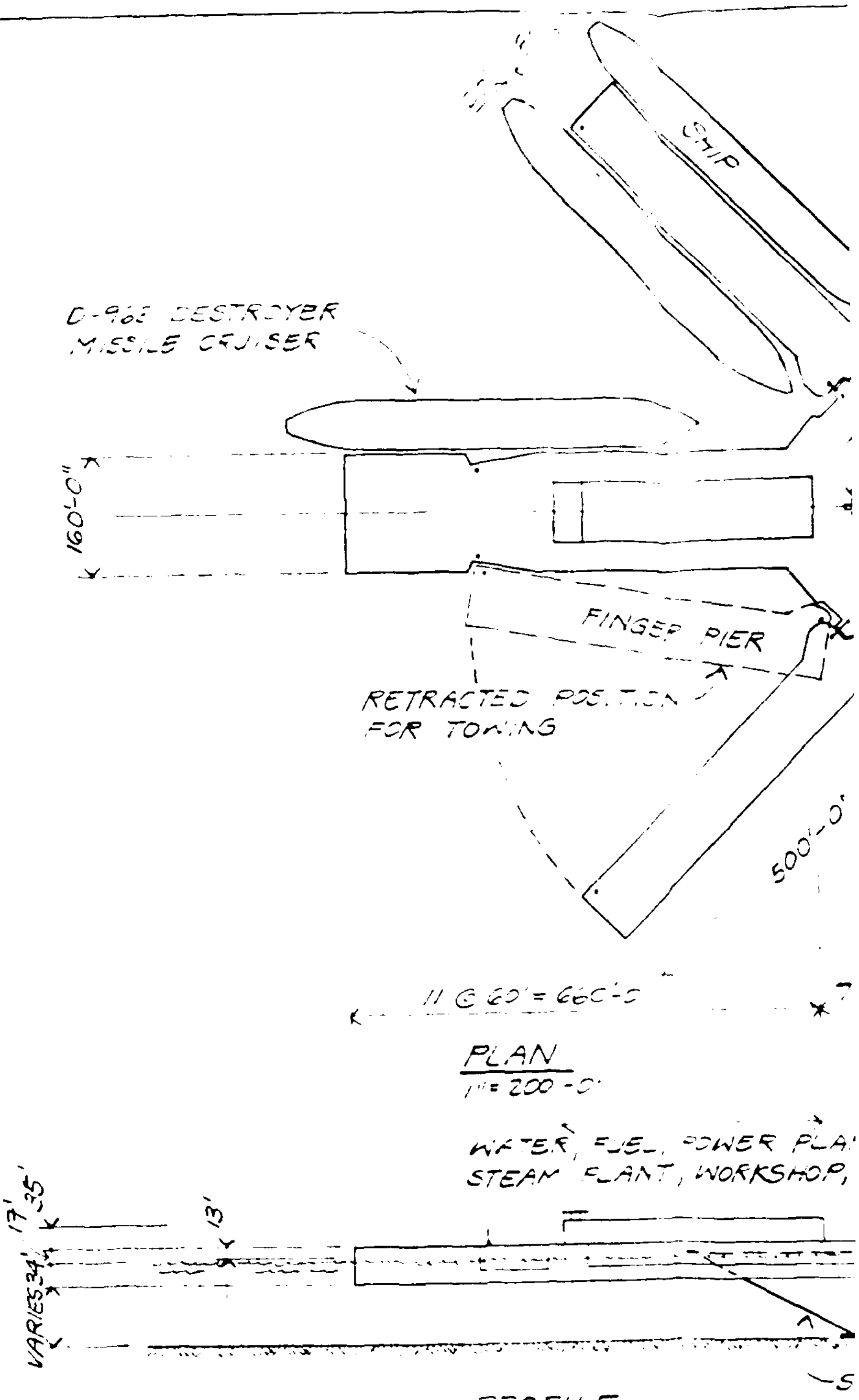

PLAN
1" = 200'-0"

PROFILE
1" = 200'-0"

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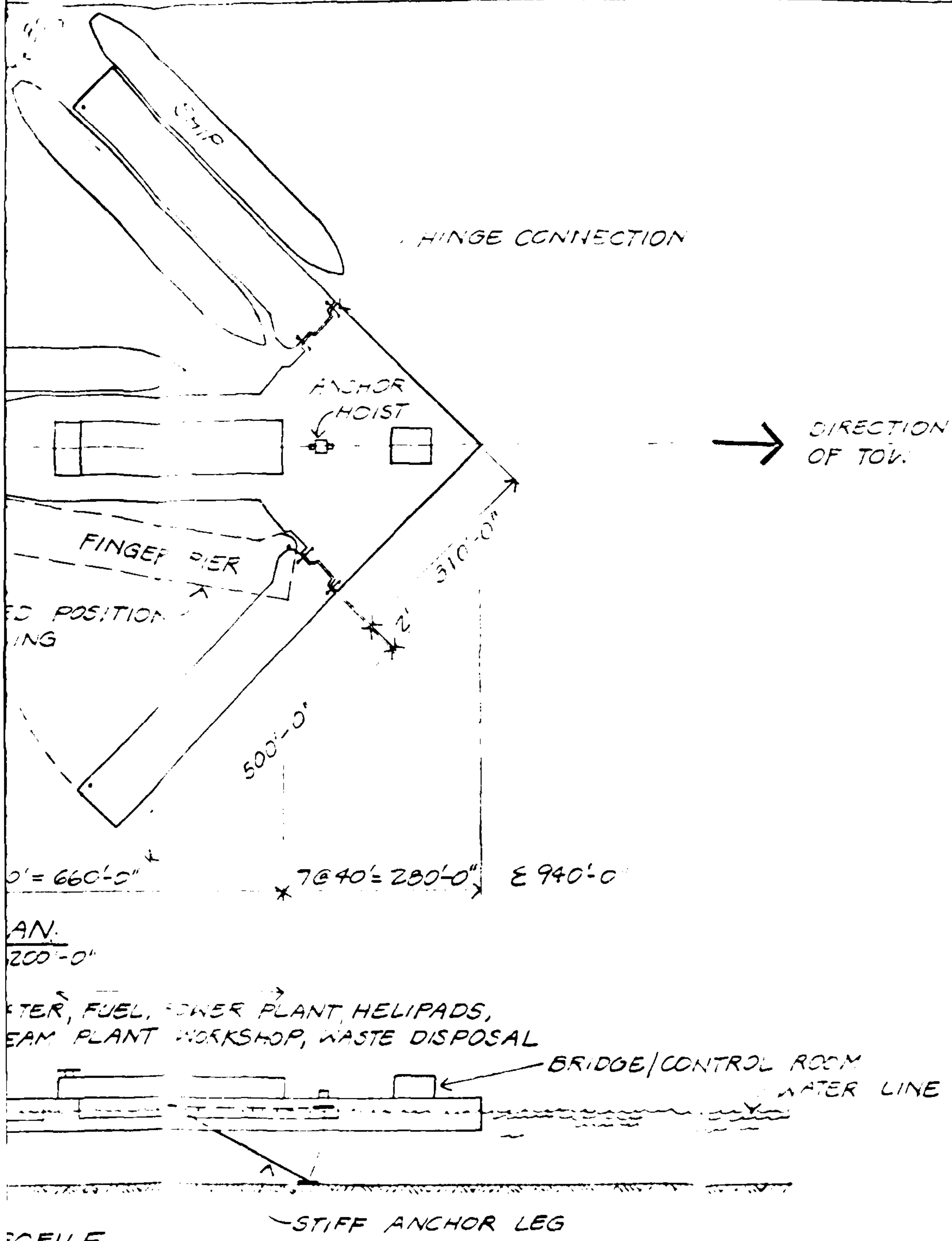

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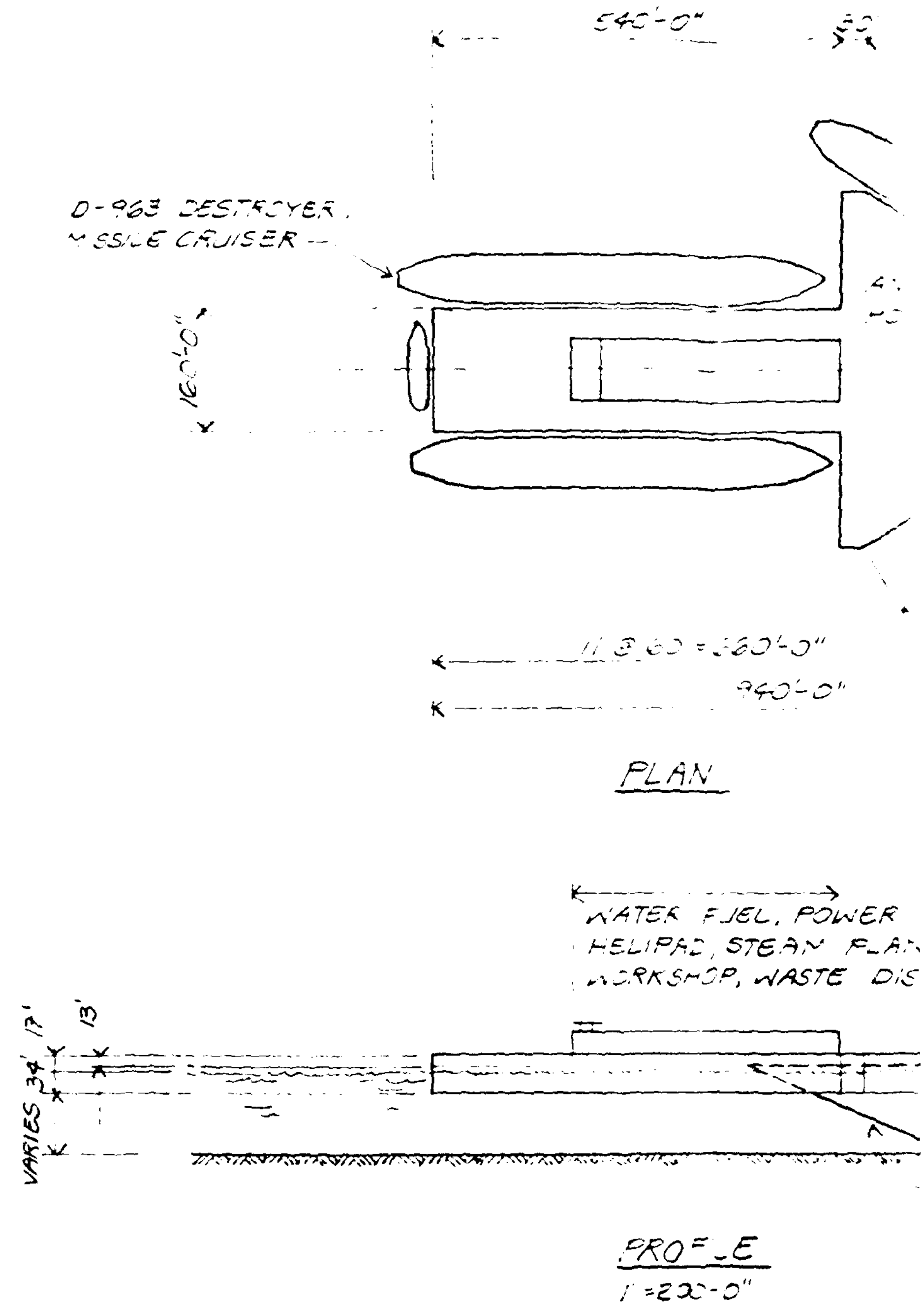
SHEET TITLE: SCHEME B

PROJECT: EXPEDITIONARY PIER

SHEET Nº: 5

PROJECT Nº
DESIGN
DRAFTING



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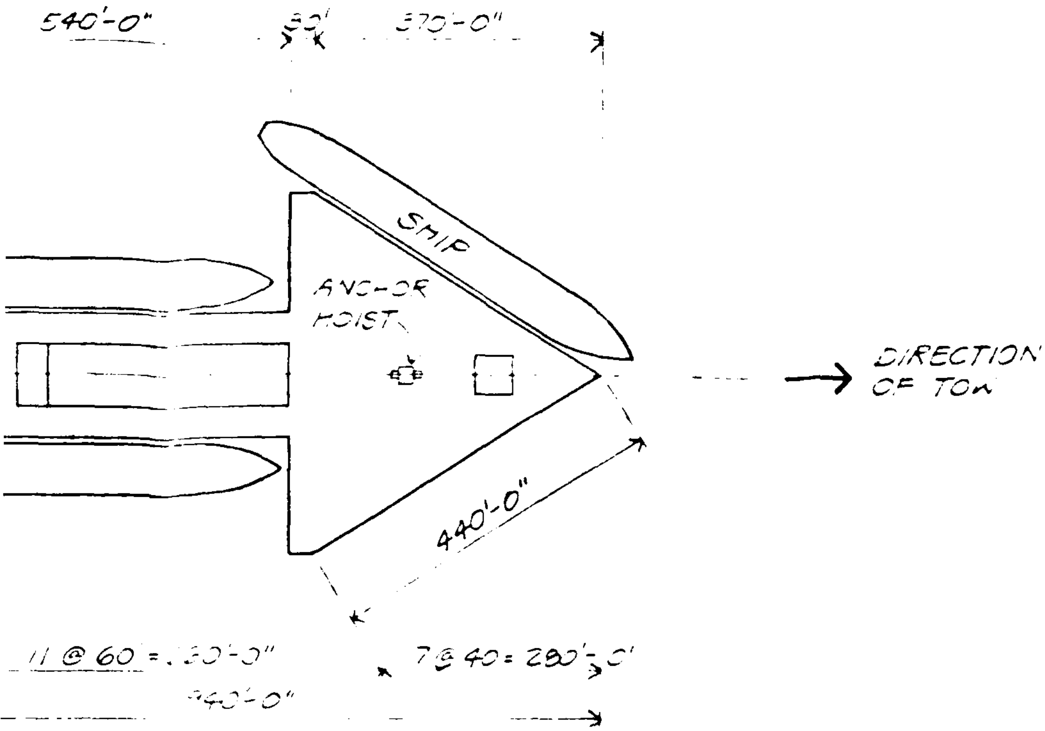
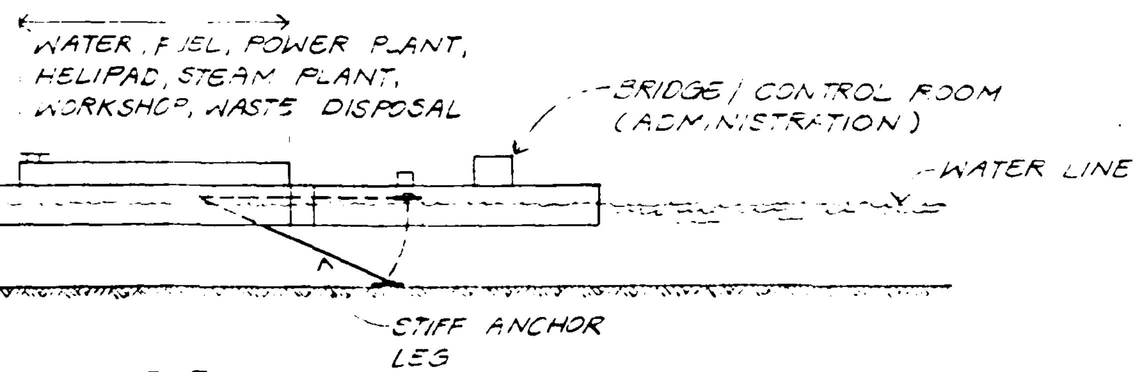


PLAN



PROFILE
1"=200'-0"

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SHEET TITLE: SCHEME C

PROJECT: EXPEDITIONARY PIER

SHEET Nº 6

PROJECT Nº
DESIGN
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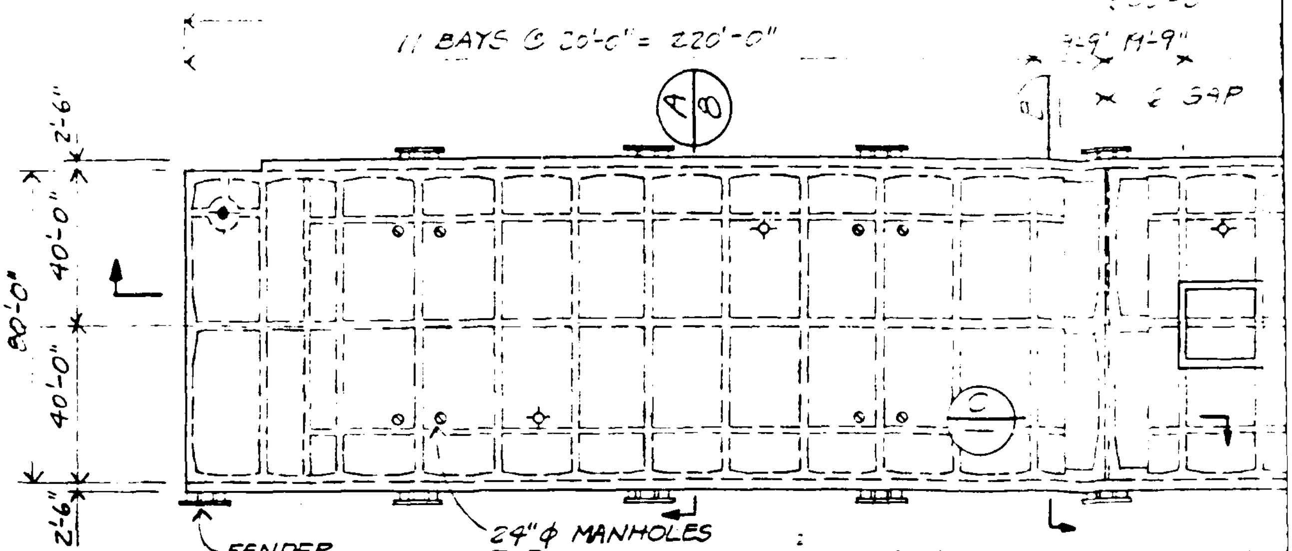
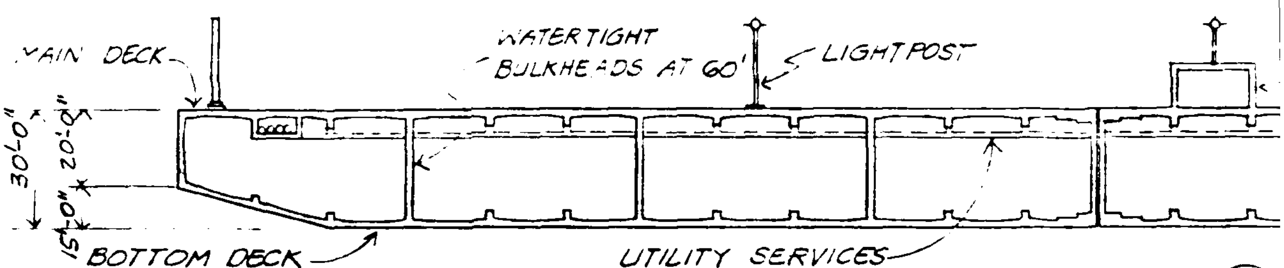
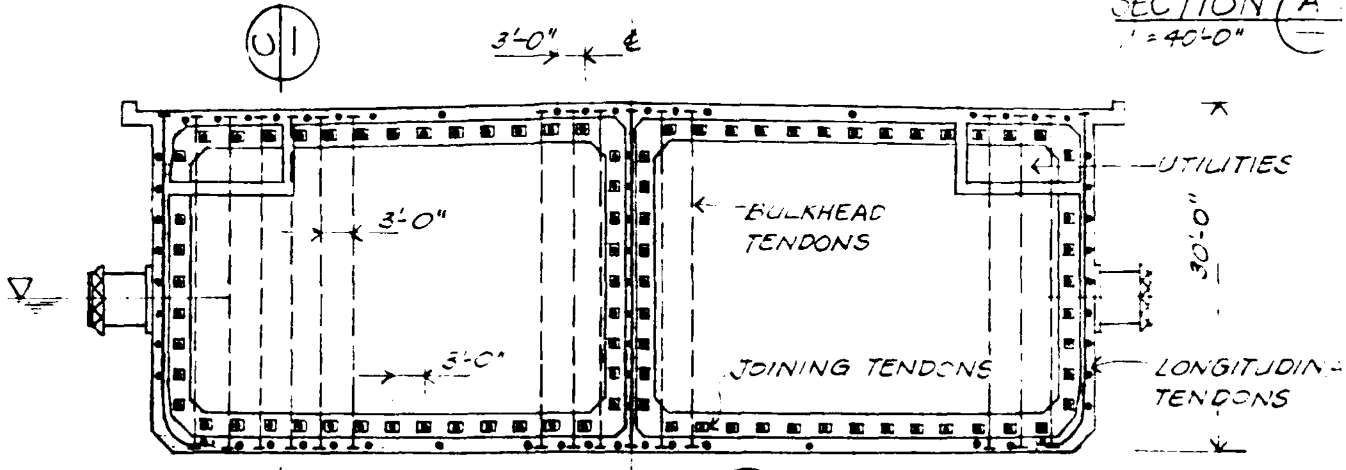


MAIN DECK AND BOTTO
1" = 40'-0"



SECTION A
1" = 40'-0"



SECTION B
3/4" = 10'-0"

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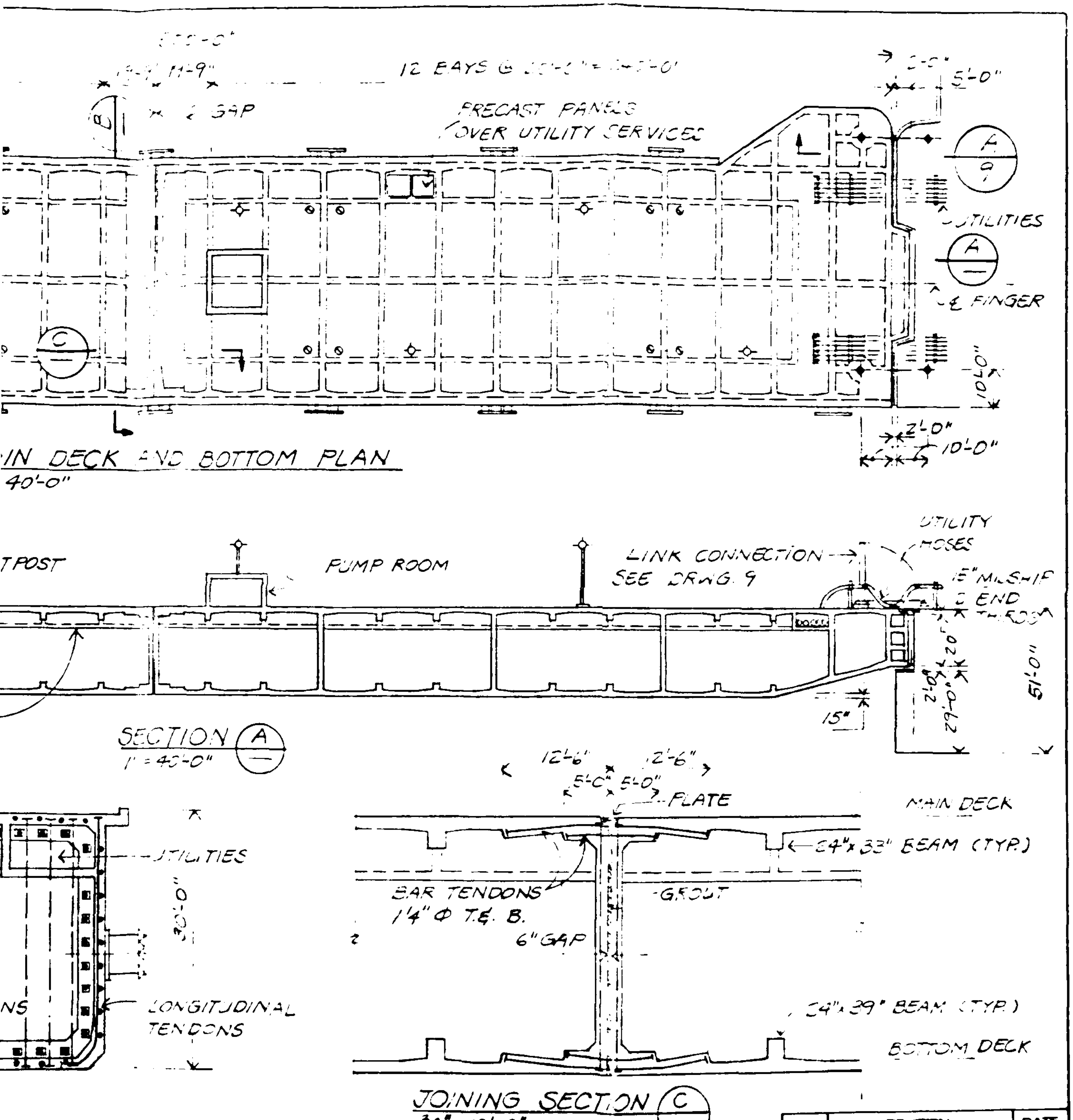

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SHEET TITLE: FINGER PIER SECTIONS & DETAILS		SHEET Nº
PROJECT: EXPEDITIONARY PIER		7

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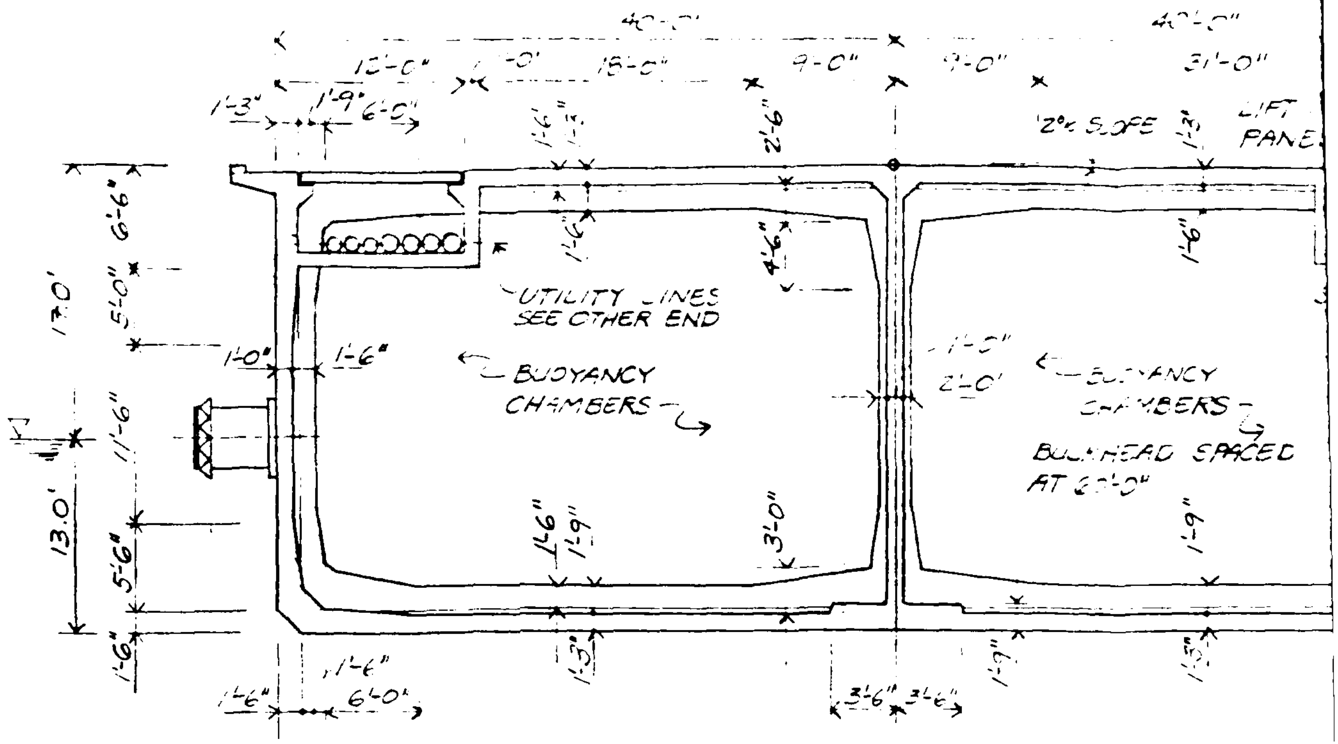
PROJECT Nº



TYPICAL FINGER CROSS SECTION (A/7)
1" = 10'-0"

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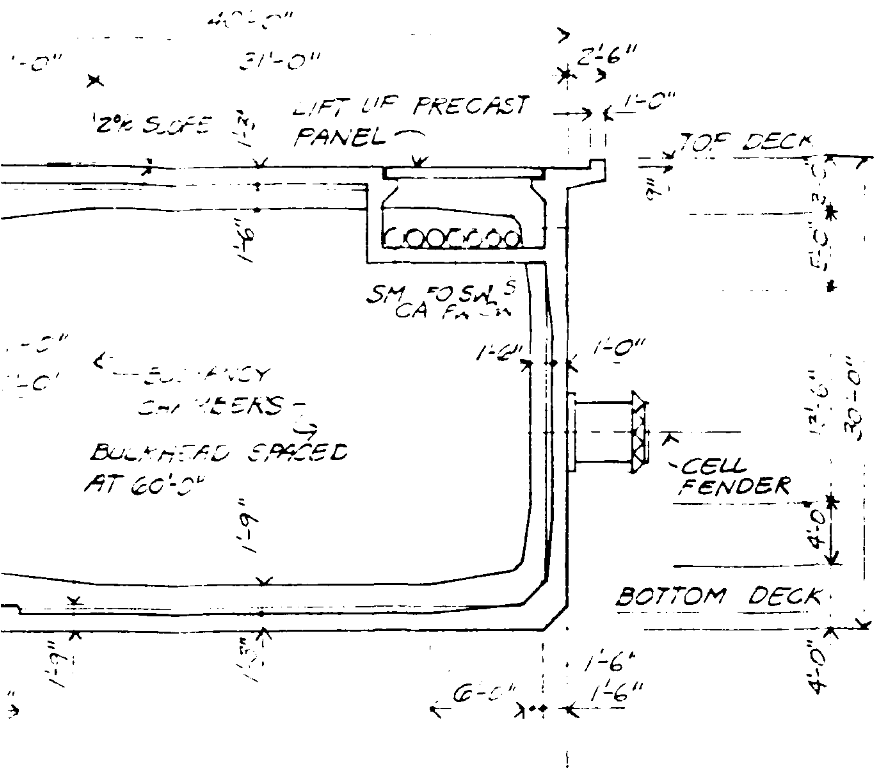

ROSS SECTION (A/7)

LEGEND:

SM	STEAM
CA	COMPRESSED AIR
FO	FUEL OIL
PW	POTABLE WATER
SW	SALT WATER
OW	OIL WASTE
S	SEWAGE

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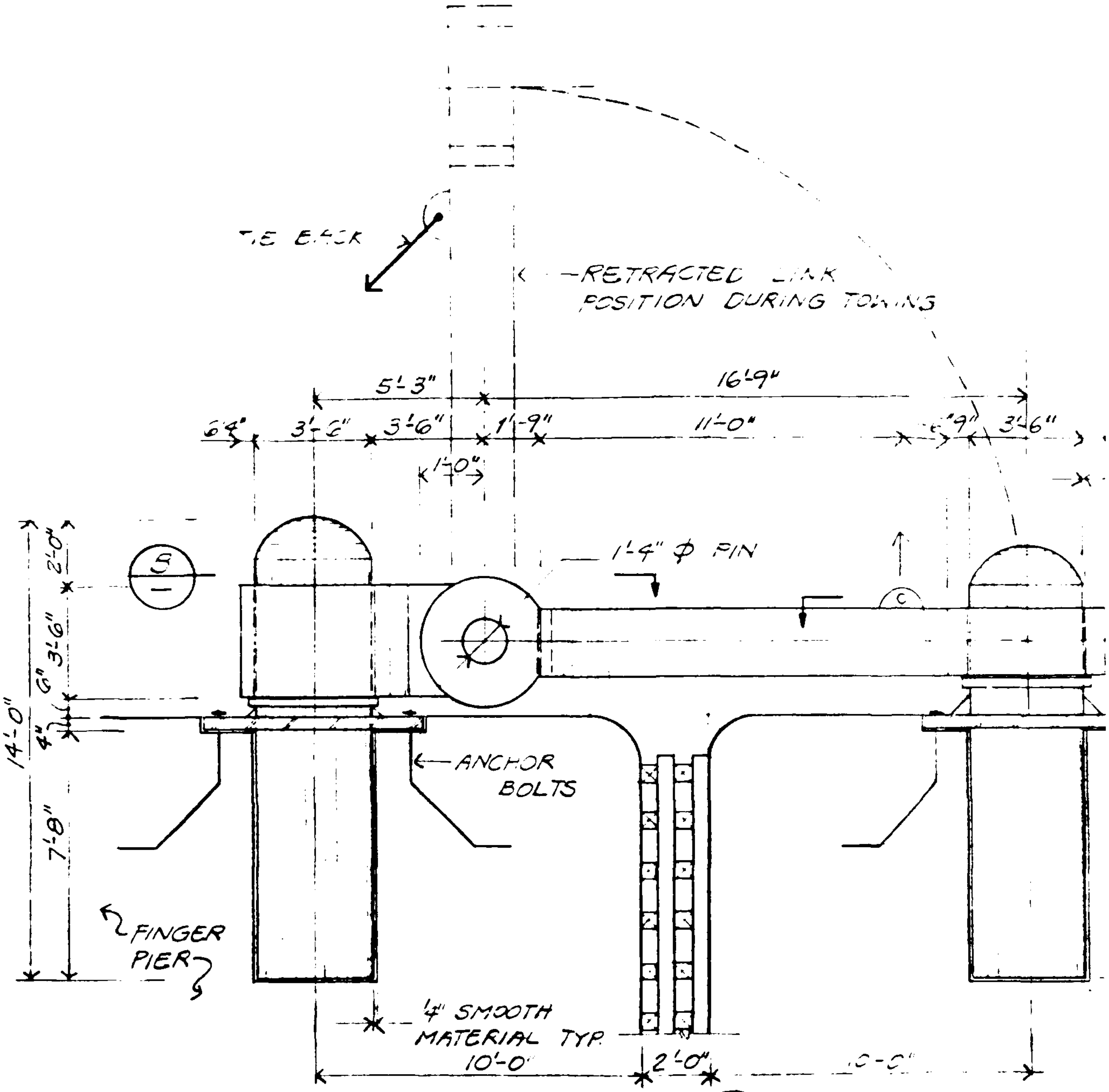
SHEET TITLE: FINGER DETAILS

PROJECT: EXPEDITIONARY PIER

SHEET Nº 8



SECTION A/7
1/4" = 1'-0"

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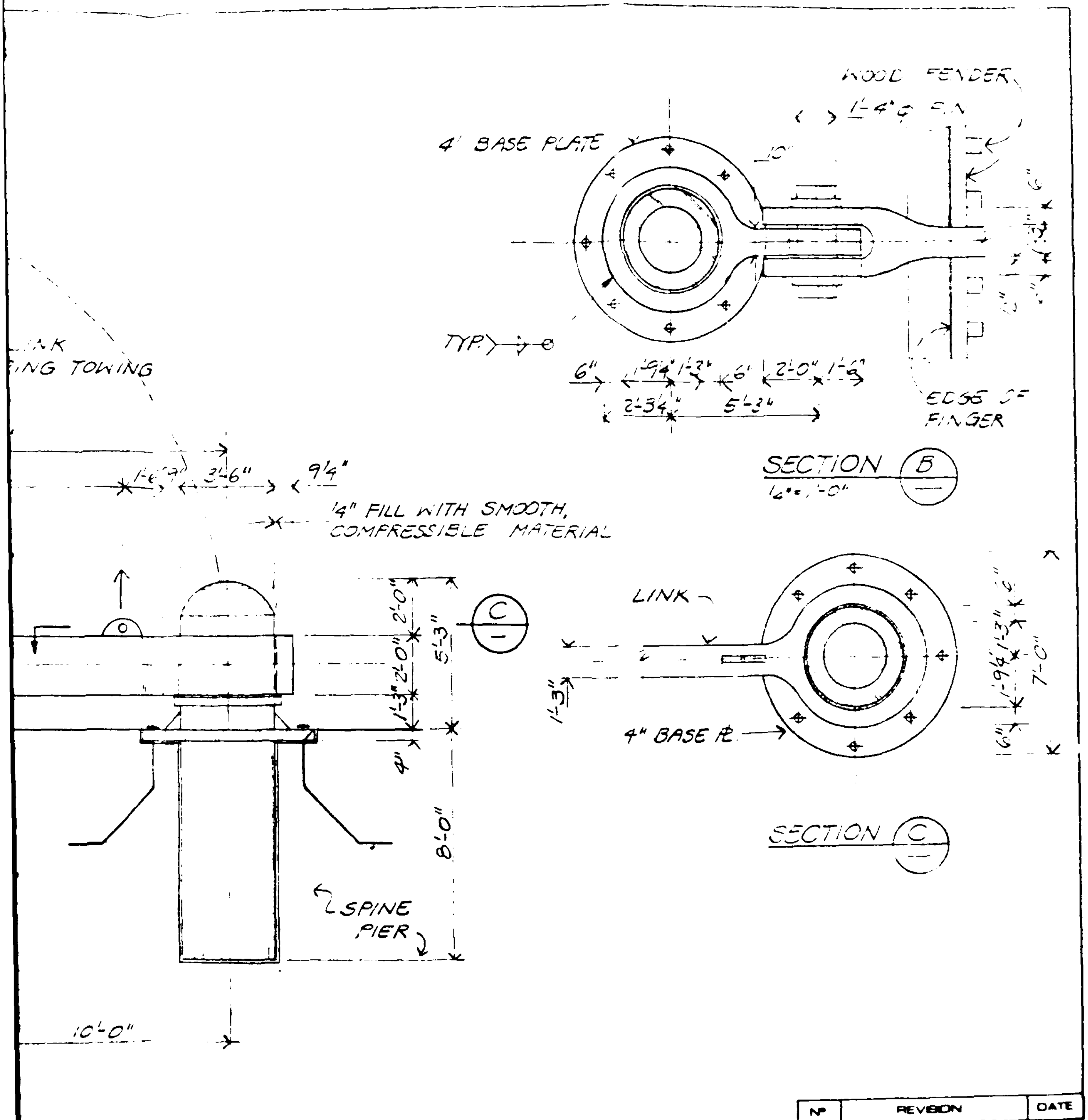

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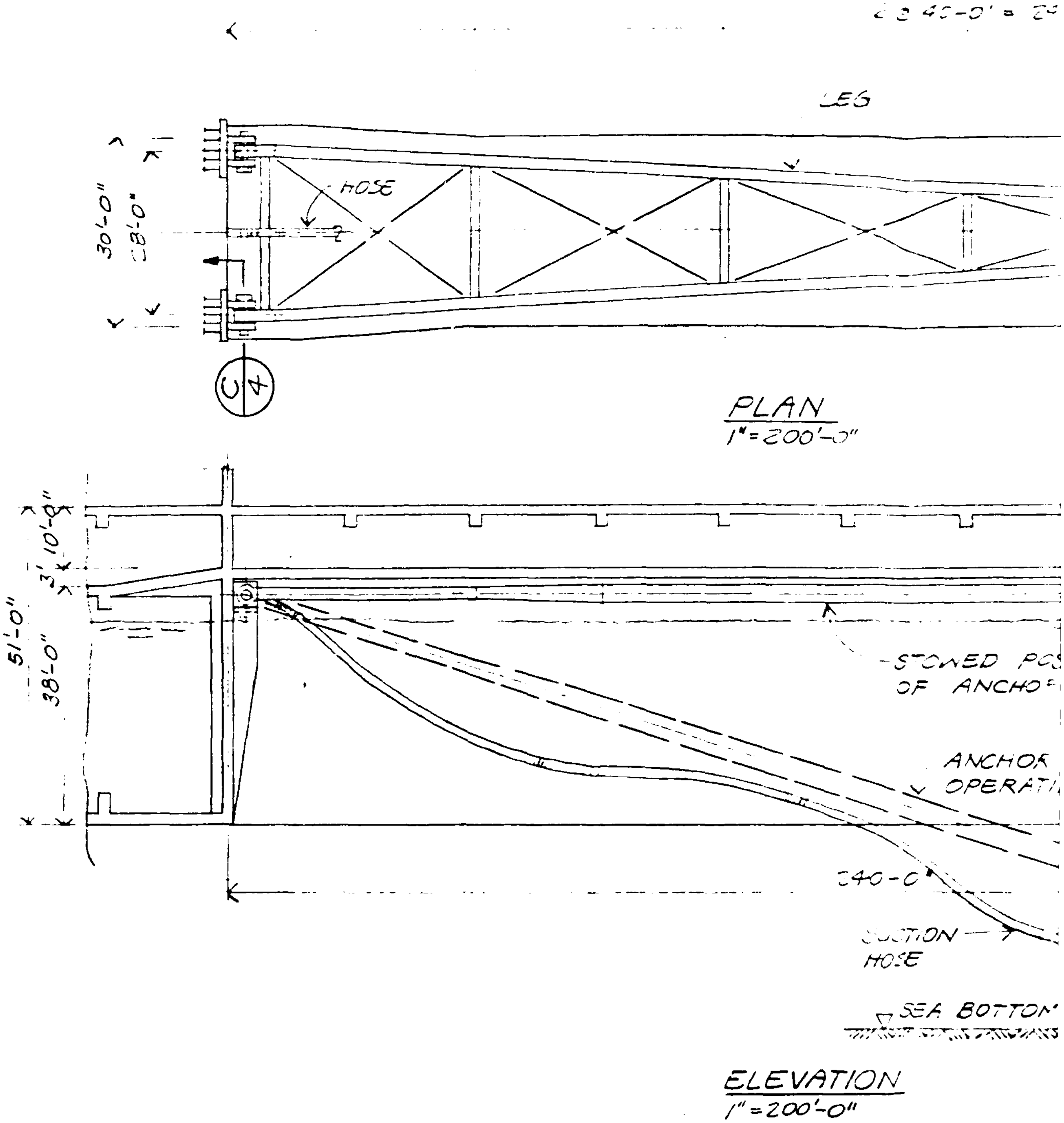
SHEET TITLE: HINGE CONNECTION FINGER/SPINE

PROJECT: EXPEDITIONARY PIER

SHEET Nº 9



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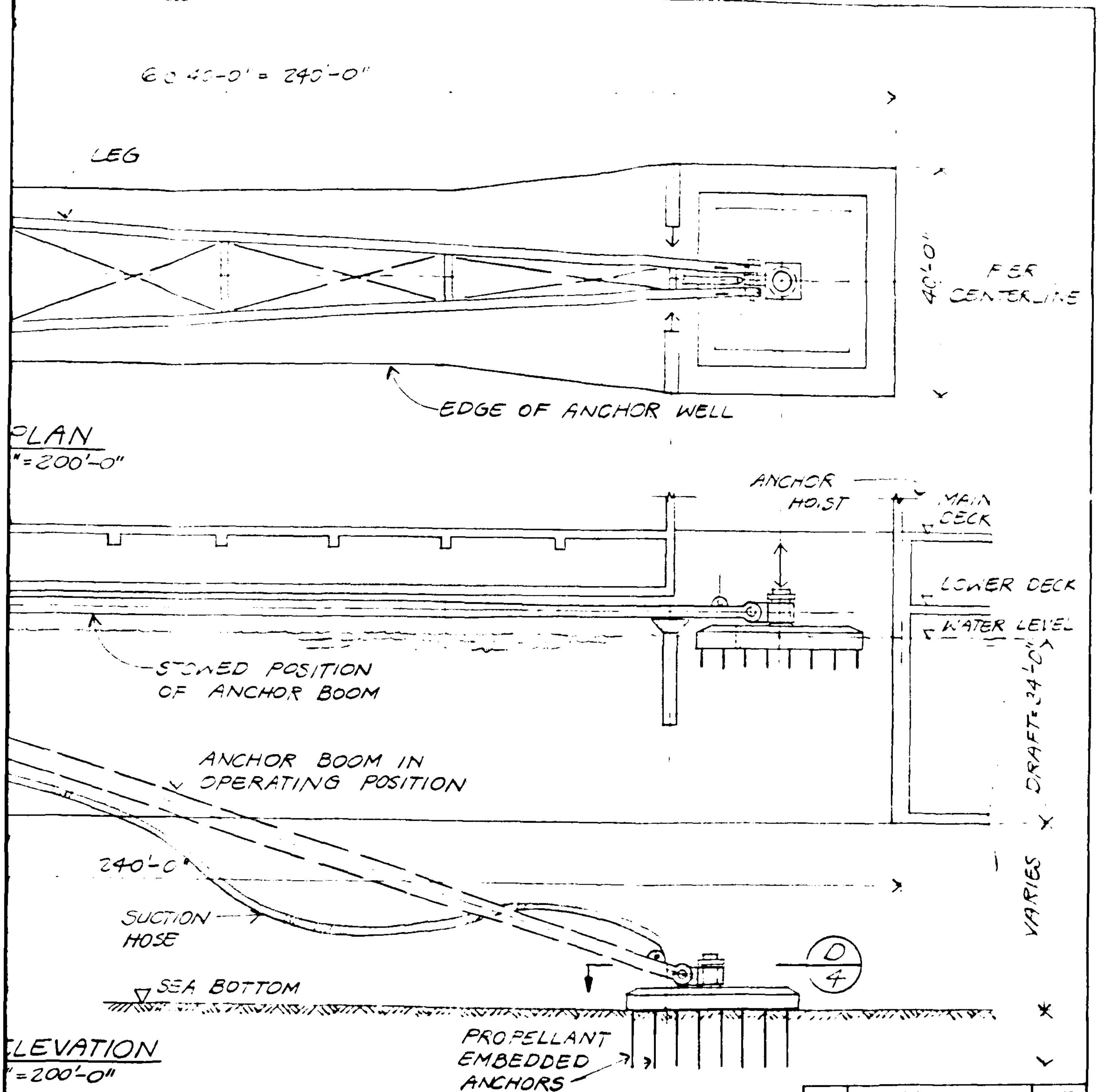

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SHEET TITLE: STIFF LEG ANCHOR

PROJECT: EXPEDITIONARY PIER

SHEET Nº: 10

PROJECT Nº
DESIGN
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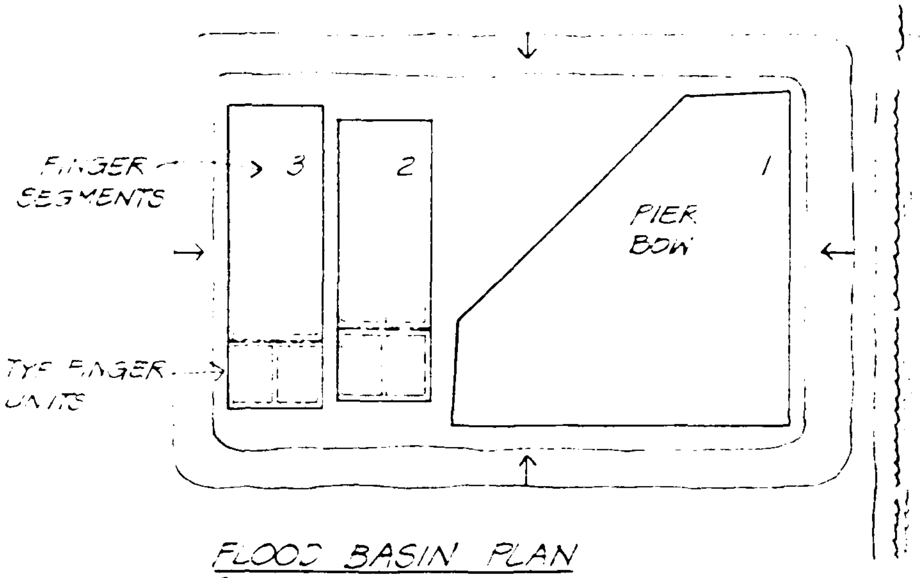
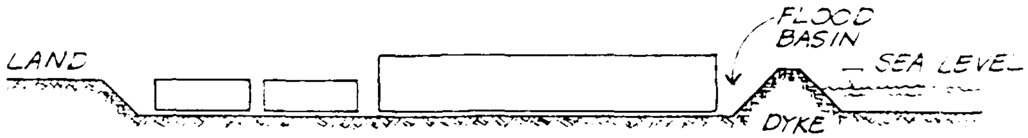


FLOOD BASIN PLAN
3/4" = 10'-0" TYP.

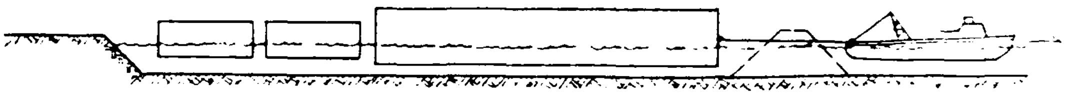


(1) CONSTRUCTION IN FLOOD BASIN

a) BUILD ONE 520'x320' BASIN

b) JOINT PRECAST UNITS OF PIER BOW (1) AND FINGER (2,3) BY POSTENSIONING

c) INSTALL UTILITY SYSTEM



(2) TOW TO ASSEMBLY SITE

a) REMOVE DYKE TO FLOAT UNITS

b) TOW TO ASSEMBLY AND FINISHING SITE

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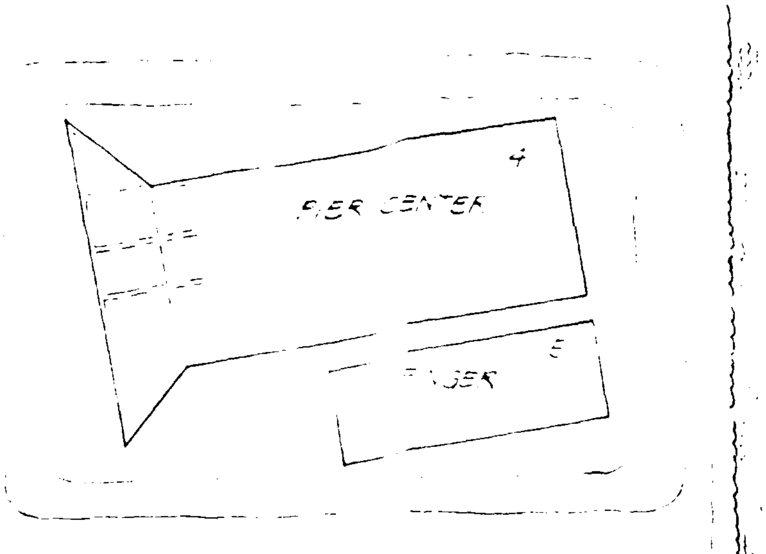
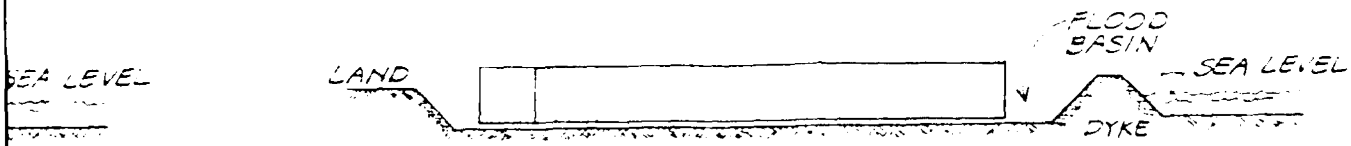


FLOOD BASIN PLAN



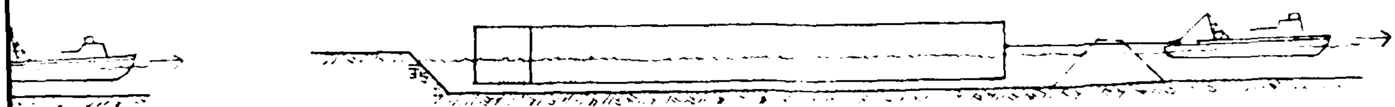
(3) CONSTRUCTION IN FLOOD BASIN

a) REBUILD DYKE

b) PUMP WATER OUT

c) JOINT PRECAST UNITS OF PIER CENTER (4) AND FINGER SEGMENT (5) BY POSTENSIONING

d) INSTALL UTILITY SYSTEM



(4) TOW TO ASSEMBLY SITE

a) REPEAT STEP 2

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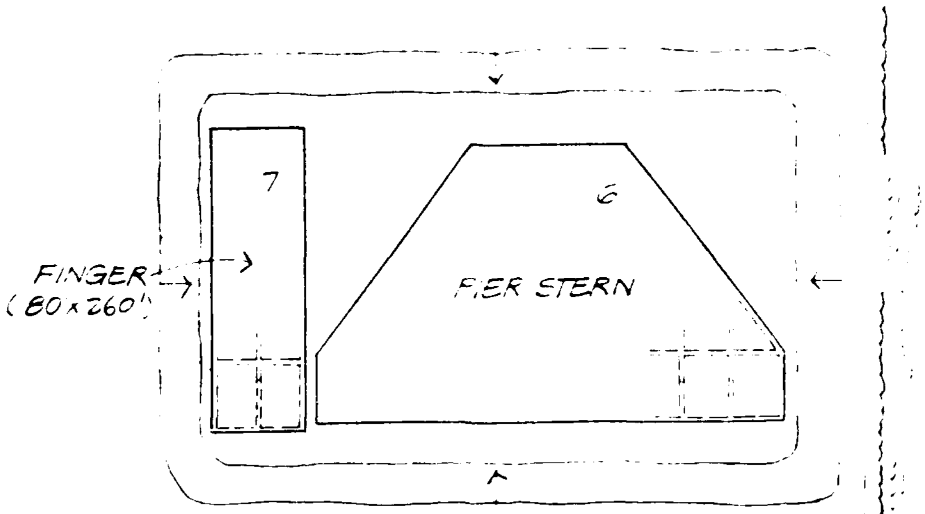
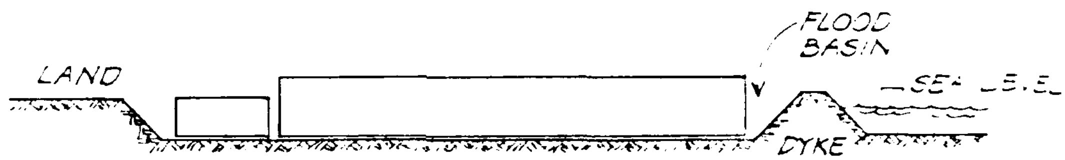
SHEET TITLE	FLOOD BASIN CONSTRUCTION METHOD
PROJECT	EXPEDITIONARY PIER
SHEET Nº	11



FLOOD BASIN PLAN



(5) CONSTRUCTION IN FLOOD BASIN

a) REPEAT STEP 3a, 3b

b) JOINT PRECAST UNITS OF PIER STERN (6) AND FINGER (7) BY POSTENSIONING

c) INSTALL UTILITY SYSTEM

d) REPEAT STEP 2

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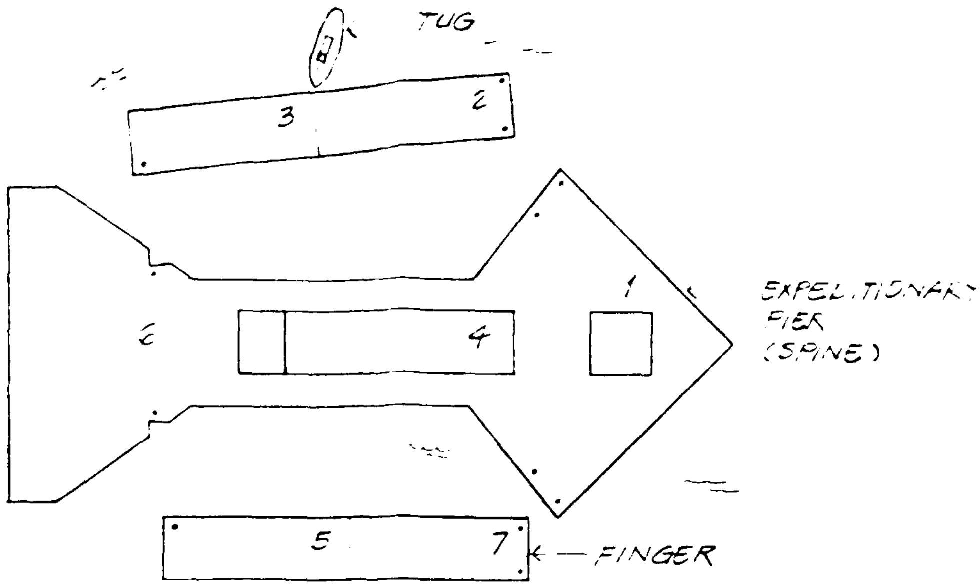
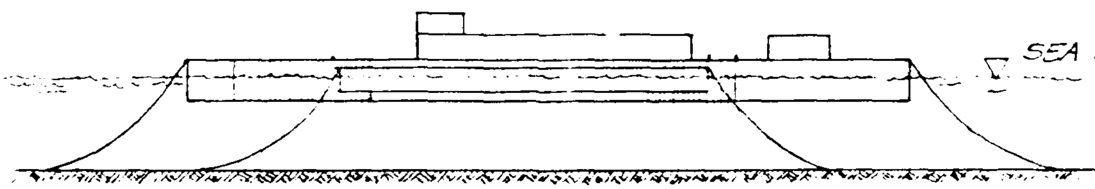


ASSEMBLY SITE PLAN



6 ASSEMBLY PIER SEGMENTS

a) JOIN EXPEDITIONARY PIER (1,4,6) AND FINGERS (2,3 FIRST THEN 5,7) BY POSTENSIONING

b) TUG FINGERS INTO SPINE

c) COMPLETE CONSTRUCTION

d) HOOK UP UTILITY LINES

e) READY FOR USE

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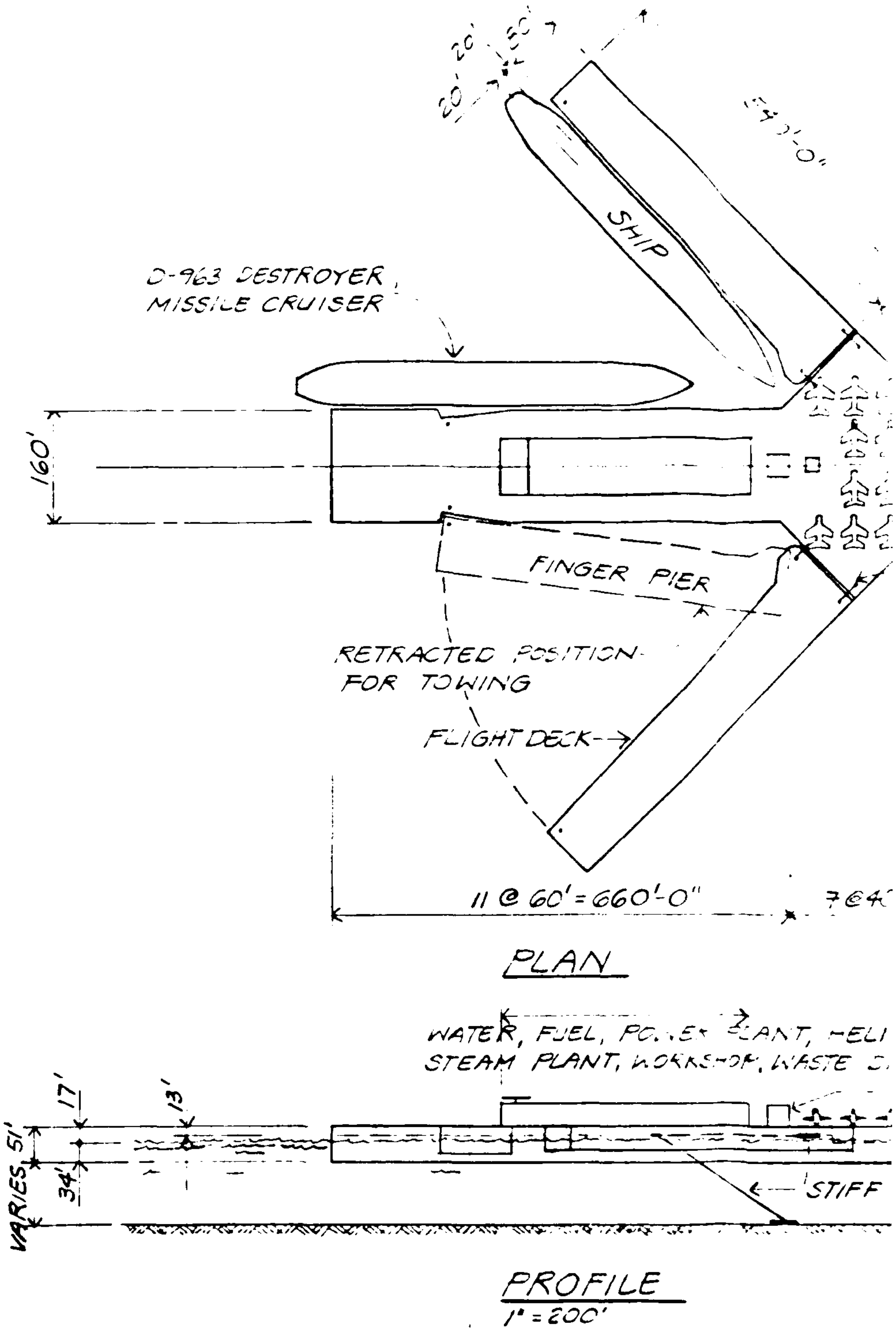
SHEET TITLE: FLOOD BASIN CONSTRUCTION METHOD

PROJECT: EXPEDITIONARY PIER

SHEET Nº 12



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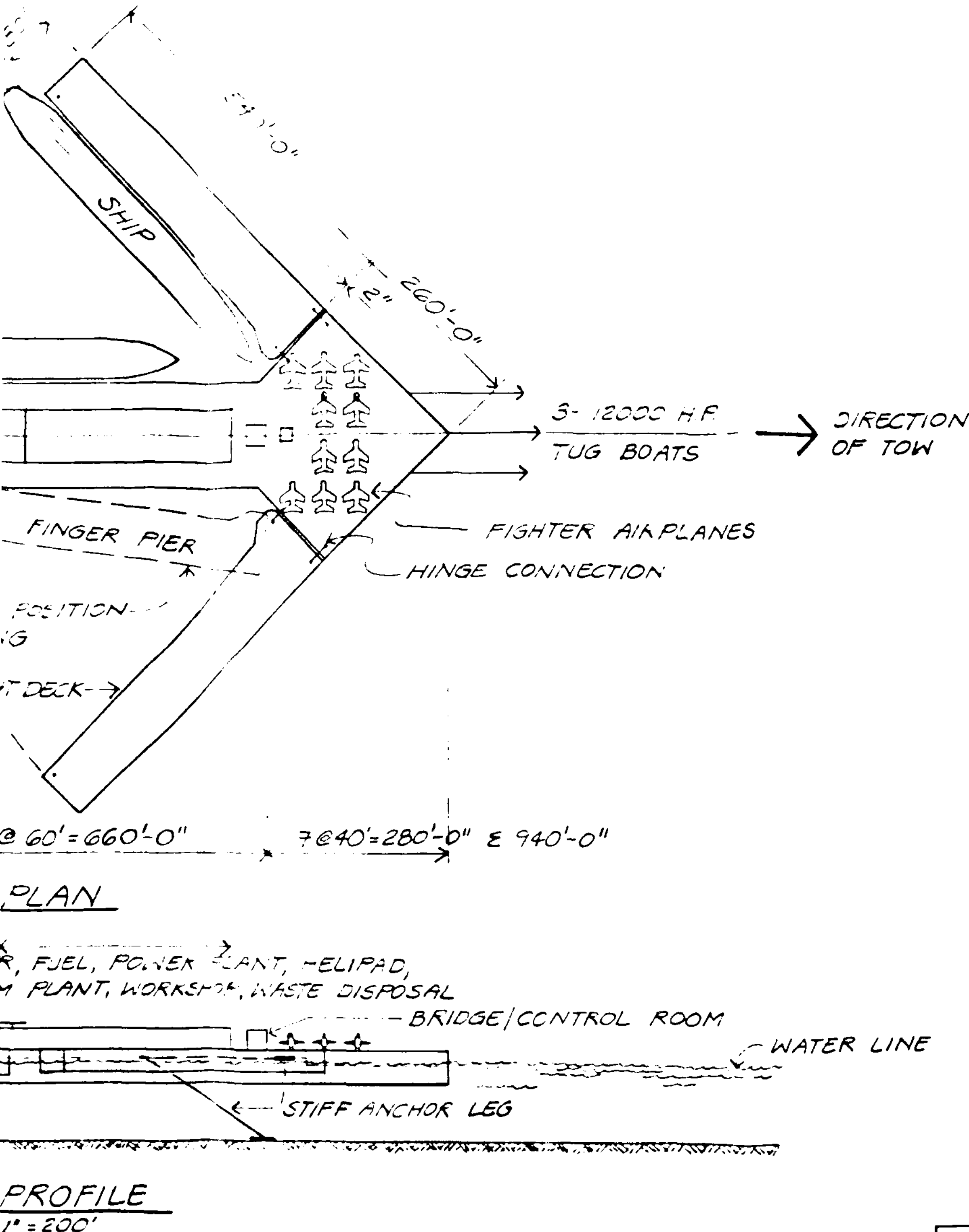

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SHEET TITLE SCHEME D

PROJECT EXPEDITIONARY PIER

SHEET Nº 13

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