U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

FINAL PROPOSAL FOR SEISMIC INSTRUMENTATION OF THE CABLE-STAYED CAPE GIRARDEAU (MO) BRIDGE

SUBMITTED TO

MISSOURI DEPARTMENT OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION
OF THE U.S. DEPARTMENT OF TRANSPORTATION

Compiled by

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Summary and Disclaimer

The proposal described herein provides a detailed scheme for seismic instrumentation of the Cape Girardeau Cable-Stayed Bridge now under construction. On October 23, 1996, a meeting was held in Washington D.C. to discuss various possible schemes of instrumentation for the bridge. The meeting was organized under the auspices of two principal organizations: the Missouri Department of Transportation [MODOT] and the Federal Highway Administration [FHWA] of the U.S Department of Transportation. These two principal organizations coordinate the design, construction and related efforts. During the meeting of October 23, 1996, the author was asked to prepare an initial draft for comment and discussion. The initial draft dated November 4, 1996 was discussed during a second meeting in Atlanta, GA on December 5, 1996. Later, on February 7, 1997, a final meeting was held in Menlo Park, Ca. Between representatives of Caltrans, LLNL and USGS to develop this final proposal using the various input put forth by the participants in all the meetings as well as from other technical staff of LLNL, Caltrans and USGS. A list of contributors and affiliations is included in this final proposal.

The hardware for instrumentation will be purchased by funding that will be put together by the two principal agencies. USGS, as part of its earthquake hazard reduction program, will provide input in deployment of instrumentation, establish a mechanism with MODOT and FHWA to maintain the instruments, retrieve, process and disseminate strong-motion response data following events in the future.

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(in alphabetical order of last names)

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1.0 Introduction

The acquisition of structural response data during earthquakes is essential to confirm and develop methodologies for analysis, design, repair and retrofitting of earthquake resistant structural systems. Particularly for urban environments in seismically active regions, acquisition of response data, from structures including lifelines such as bridges, by using seismic instrumentation, is one of the basic requirements for a thorough investigation of the effects of earthquakes on the structures. In order to understand the structural responses thoroughly, in addition to structural arrays which should include sensors for soil-structure interaction (SSI) effects, it is necessary to record ground motions at the free-field in the vicinity of the structures. The New Madrid area, the location of the 1811–1812 New Madrid earthquakes, is a seismically active region requiring earthquake hazard mitigation programs including those related to investigation of strong shaking of structures and the potential for ground failures in the vicinity of structures. Discussion of seismicity of the area can be found in References 1 and 2.

The objective of this proposal is to develop possible schemes of seismic instrumentation to be deployed on and in the vicinity of the new Cape Girardeau Bridge (MO) now under construction. Early planning of seismic instrumentation schemes is a necessity in order to cover installation of basic hardware during the construction phases (such as conduits and cables to interconnect the sensors to recorders and conduits for deployment of downhole accelerometers). It is important to note also the proposed instrumentation is for strong-motion recording and not for low-amplitude weak motions. For low-amplitude weak motions, special purpose temporary deployment schemes should be adopted.

In addition to other objectives which require special purpose instruments and hardware, for seismic engineering studies, in general, three different objectives are sought. In planning for the overall scheme, it is important to clearly identify these objectives:

1. Instrumentation of the Superstructure and Pier Foundations.
2. Instrumentation of the free-field in the vicinity of the structure including those related to downhole measurements and horizontal spatial arrays to assess the differential motions at the piers of the long span structure.
3. Ground failure arrays in the vicinity of the structure.

The scope of this proposal is limited to description of seismic instrumentation covering the first two objectives. Details of geotechnical considerations related to the bridge are provided in Reference 2.

2.0 General Considerations

2.1 Goals for the Seismic Array

The general locations where sensors are essential are marked in Figure 1. With the detailed instrumentation scheme outlined below, the following goals will be met:

a. Detection of the structural response (of the caissons, tower, deck). Whenever applicable, sufficient additional sensors for soil-structure interaction (SSI) are added.
b. Spatial variation of ground motion along the total span (3956 ft ~ 1206 m) of the bridge (longitudinal, transverse and vertical).

2.2 Strategies for Housing the Recording Systems for the Seismic Array

There are three possible strategies for implementation of the structural array:

A. A new approach to seismic instrumentation scheme appears to be feasible by taking advantage of the new state-of-the-art recording hardware that includes or can be ordered with GPS capability. GPS capability can be used for common-time recording of events when more than one recording system are used at different locations of a structure such as the long-span cable-stayed Cape Girardeau bridge. Thus, cables and appropriate connections are minimized. Normally, since a bridge is inherently a long span structure, extensive and expensive cabling (and conduits) would be required to interconnect various sensors to the recorder and various recorders to one another. The proposed or alternative (recording system) hardware can be configured to provide combinations of 3-18 channels at different locations (Bent 1, Pier 2, Pier 3, Pier 4 and Pier 15). The recommended strategy would be more economical than having all recording systems in one or two locations with various sensors deployed at different piers, caisson tops, towers and deck connected to the recorders with long cables. The downside of this approach is that for maintenance of the recording systems, several stops and access arrangements would be required
B. All recording systems be placed in one location (e.g. In the room at Pier 2 or 3). This has advantages from maintenance point of view and future transmission of data by phone lines or telemetry such that all data can be downloaded or transmitted from one location. The negative of this approach is the extensive "heavy duty" cabling required between sensors and recorders.
C. All recording systems up to and including Pier 5 be placed on ground in a secure housing at Bent 1 (Missouri side) or Pier 2 or Pier 3. All recording systems from Pier 6 through Pier 15 be located in a secure housing on the Illinois side. This will also require extensive cabling..

2.3 Special Considerations for Weather

In addition, it is essential to consider the general weather requirements for the instrumentation. Cape Girardeau area often is subjected to severe thunderstorms and lightning. Therefore, at each step of the way, lightning protection for the seismic instruments will be required. This is available for the type of recording systems that are cited later on in the proposal. However, special transient protection hardware is necessary for the downhole accelerometers.

3.0 Permanent Seismic Instrumentation for Cape Girardeau Bridge

3.1. General

In Figures 1 through 10, general and detailed strong-motion instrumentation of the Cape Girardeau Bridge and associated free-field arrays are described. Figure 1 shows the general locations where sensors should be deployed in order to record motions of and assess the following responses of the bridge and its vicinity:

a. Free-field motions at the surface and downhole locations reaching competent (i.e. unweathered) rock.
b. Overall motion of the cable-stayed bridge.
c. Motions of extreme ends of the bridge as well as intermediate pier locations to provide data for the translational, torsional, rocking and translational SSI at the foundation levels. This setup will also provide insight into the horizontal and vertical spatial variation of ground motion.
d. Motions of the two towers to assess their translational and torsional behavior – relative to the caissons and deck levels.
e. Motions of the deck to assess the fundamental and higher mode translational (longitudinal, transverse and vertical) and torsional components.

In this particular description, no specific downhole arrays below the caissons of Piers 2 and 3 are considered. The argument for this is that the motions at the free-field (surface and downhole) in the vicinity of Bent 1 (on the Missouri side) and Pier 15 (on the Illinois side) **can be justifiably used as surrogate motions** to perform detailed analyses of the bridge deck, piers with towers, towers, piers without towers and caisson tops. Also, no load cells for the cables are included. If desired, these could be added on to the overall list and the costs associated with the load cells also can be summed up to the rest of the hardware detailed below.

However, because of the changes in interlayering of soft and hard rock at Piers 4 and 5, we recommend that three triaxial accelerographs (two downhole and one surface accelerographs) be deployed at approximately 100 ft to the North or South of Pier 5. The instrumentation costs for this additional array is included in the cost estimates that follow.

No installation costs are included in this proposal. Such costs will require separate evaluation following decisions to adopt parts or whole of the specific instrumentation proposed.

3.2. Specifics

Figure 2 shows Bent 1 where only a triaxial unit is planned. However, in the immediate vicinity of Bent 1 and Pier 15, within a distance of 100-300 m., it is recommended to provide free-field arrays as shown in Figure 3. These free-field locations, without any feedback from the structure, will be essential in providing the ground motions that may be used as a surrogate for the various piers of the bridge and also for convolution and deconvolution studies of the free-field ground motion. Specific sensors, the particular orientations desired are shown on each figure and are also summarized in Table 1. Also in Table 1, approximate costs of each unit is provided so that a rough estimate of total cost for required hardware can be made.

Also, as repeated above, because of the changes in interlayering of soft and hard rock at Piers 4 and 5, we recommend that **three triaxial accelerographs (two downhole and one surface accelerographs) be deployed at approximately 100 ft to the North or South of Pier 5.**

Figures 4-8 show instrumentation at Piers 2, 3 and 4. The specific caisson instrumentation is shown in Figures 4-7. Caisson 2 will be equipped with one vertical sensors only to detect vertical translational and additional horizontal sensors to detect translational (longitudinal and transverse) motions. Caisson 3 will be equipped with one vertical sensors at each of the 3 corners to detect vertical translational and rocking motions, if any and additional horizontal sensors to detect translational (longitudinal and transverse) motions.

Figure 8 shows deck level instrumentation for Pier 4. Essentially, this will be repeated for Piers 5, 10 and 15. At each of the the foundation levels of Piers 5, 10 and15, a triaxial accelerograph is planned. For specific piers, this might be modified if so desired.

Figures 9-11 show general instrumentation scheme for deck location at the centerline (CL) of the cable-stayed deck, and at the "quarter" locations (L1, L2, R1 and R2).

3.3. Approximate Total Cost for the Hardware

The approximate total cost for the hardware for the instrumentation scheme presented herein is summarized in Table 2. The total shown ($360K) provides an insight of the cost levels that is envisaged. The configuration of the instrumentation can be changed in any other fashion desired and estimates of the total can be easily revised.

To repeat, the cost estimates do not include installation costs. Similarly, the estimates do not include costs for dedicated phone lines (if desired) or telemetry system (if desired) for communicating with the recording systems and transfer of data to another location. However, these can be detailed and added later on once the scheme of instrumentation is finalized and the location of the recording systems are decided upon.

4.0 Conclusions and Recommendations

This final proposal details the seismic instrumentation scheme for the Cape Girardeau Cable-Stayed Bridge now under construction. **The scheme described provides extensive strong-motion response recording capability to facilitate different types of studies and to assess the performance of the subject structure during strong-motion events.** *It is noted that the instrumentation scheme recommended herein can also record low-amplitude motions (M~2-3). These motions can be used to estimate site-specific strong-motion events.* However, it is recommendeed that the system be thought of as necessary for recording responses of the structure to moderate to large events.

References

1. Nuttli, O. W., 1974, Magnitude-recurrence relation for central Missippi Valley earthquakes, Seismological Society of America Bulletin, 64, pp. 1189-1207.

2. ---------, Geotechnical Seismic Evaluation Proposed New missippi River Bridge (A-5076) Cape Girardeau, Mo, Woodward-Clyde Consultants Report 93C8036-500, March 1994.

APPENDIX A. SYMBOLS USED

Symbols for Direction of Sensors:

L: Longitudinal direction of the bridge
T: Transverse direction of the bridge
V: Vertical

Symbols for type of Sensors:

LC: Load Cell (not recommended in this proposal)
FBA: Force-balance accelerometer
Uniaxial [FBA-11],
Biaxial [FBA-22],
Triaxial [FBA-23],
Traxial Downhole FBA-23DH

TABLE 1. CAPE GIRARFEAU BRIDGE INSTRUMENTATION

LOCATION			Type of Instruments	PURPOSE	NO	$ (K)
BENT 1			FBA-23(triaxial)	Bent 1 motions(L,V,T)	1	$ 3.00
PIER 2	Top of Tower	South End	FBA-22(biaxial)	Tower top motions (L,T)	1	$ 2.00
		North End	FBA-22(biaxial)	Tower top motions (L,T)	1	$ 2.00
	Mid-Tower	South End	FBA-22(biaxial)	Mid-tower motion (L,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Mid-tower motion (T)	1	$ 1.00
	Deck Level	South End	FBA-22(biaxial)	Deck motion (L,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck motion (L)	1	$ 1.00
	Caisson Top	N-E	FBA-23(triaxial)	Caisson top (L,V,T) & SSI	1	$ 3.00
PIER 3	Top of Tower	South End	FBA-22(biaxial)	Tower top motions (L,T)	1	$ 2.00
		North End	FBA-22(biaxial)	Tower top motions (L,T)	1	$ 2.00
	Mid-Tower	South End	FBA-22(biaxial)	Mid-tower motion (L,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Mid-tower motion (T)	1	$ 1.00
	Deck Level	South End	FBA-22(biaxial)	Deck motion (L,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck motion (L)	1	$ 1.00
	Caisson Top	N-E	FBA-23(triaxial)	Caisson top (L,V,T) & SSI	1	$ 3.00
		N-W	FBA-11(uniaxial)	Caisson top (V) & SSI	1	$ 1.00
		S-W	FBA-22(biaxial)	Caisson top (L,V) & SSI	1	$ 2.00
PIER 4	Caisson Top	N-E	FBA-23(triaxial)	Caisson top (L,V,T) & SSI	1	$ 3.00
		N-W	FBA-11(uniaxial)	Caisson top (V) & SSI	1	$ 1.00
		S-W	FBA-22(biaxial)	Caisson top (L,V) & SSI	1	$ 2.00
	Deck Level	South End	FBA-22(biaxial)	Deck motion (L,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck motion (L)	1	$ 1.00
PIER 5	Deck Level	South End	FBA-22(biaxial)	Deck motion (L,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck motion (L)	1	$ 1.00
	Foundation		FBA-23(triaxial)	Foundation(L,V,T) &SSI	1	$ 3.00
DECK	L1	South End	FBA-22(biaxial)	Deck (V,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck (V)	1	$ 1.00
	L2	South End	FBA-22(biaxial)	Deck (V,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck (V)	1	$ 1.00
	R1	South End	FBA-22(biaxial)	Deck (V,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck (V)	1	$ 1.00
	R2	South End	FBA-22(biaxial)	Deck (V,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck (V)	1	$ 1.00
PIER 10	Deck Level	South End	FBA-22(biaxial)	Deck motion (L,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck motion (L)	1	$ 1.00
	Foundation		FBA-23(triaxial)	Foundation(L,V,T) &SSI	1	$ 3.00
PIER 15	Deck Level	South End	FBA-22(biaxial)	Deck motion (L,T)	1	$ 2.00
		North End	FBA-11(uniaxial)	Deck motion (L)	1	$ 1.00
	Foundation		FBA-23(triaxial)	Foundation(L,V,T) &SSI	1	$ 3.00

FREE-FIELD	MISSOURI SIDE	Surface	FBA-23(triaxial)	At Surface	1	$ 3.00
	(See Note 1)	Downhole	FBA-23DH(triaxial)	At mid-depth *(See Note 2)*	1	$ 11.00
		Downhole	FBA-23DH(triaxial)	At Solid Rock *(See Note 3)*	1	$ 11.00
FREE-FIELD	ILLINOIS SIDE	Surface	FBA-23(triaxial)	At Surface	1	$ 3.00
	(See Note 4)	Downhole	FBA-23DH(triaxial)	At mid-depth *(See Note 5)*	1	$ 11.00
		Downhole	FBA-23DH(triaxial)	At Solid Rock*(See Note 6)*	1	$ 11.00
FREE-FIELD	PIER 5	Surface	FBA-23(triaxial)	At Surface	1	$ 3.00
	(See Note 7)	Downhole	FBA-23DH(triaxial)	At mid-depth*(See Note 8)*	1	$ 11.00
		Downhole	FBA-23DH(triaxial)	At Solid Rock*(See Note 9)*	1	$ 11.00
FOOTNOTES:						
1	At 50-100 m from the bent	Bent 1				
2	At bottom of soil layers					
3	At Vs>7000 ft/s or 100 ft below the soil/rock interface					
4	At 50-100 m from Pier 15					
5	At 3 m below liquefiable zone		(N>30)			
6	At Vs>7000 ft/s or 100 ft below the soil/rock interface					
7	At 100 ft North or South from Pier 5					
8	At soil/rock interface (top of weathered rock)					
9	At Rock (same as 3 or 6)					

ADDITIONAL NOTES:

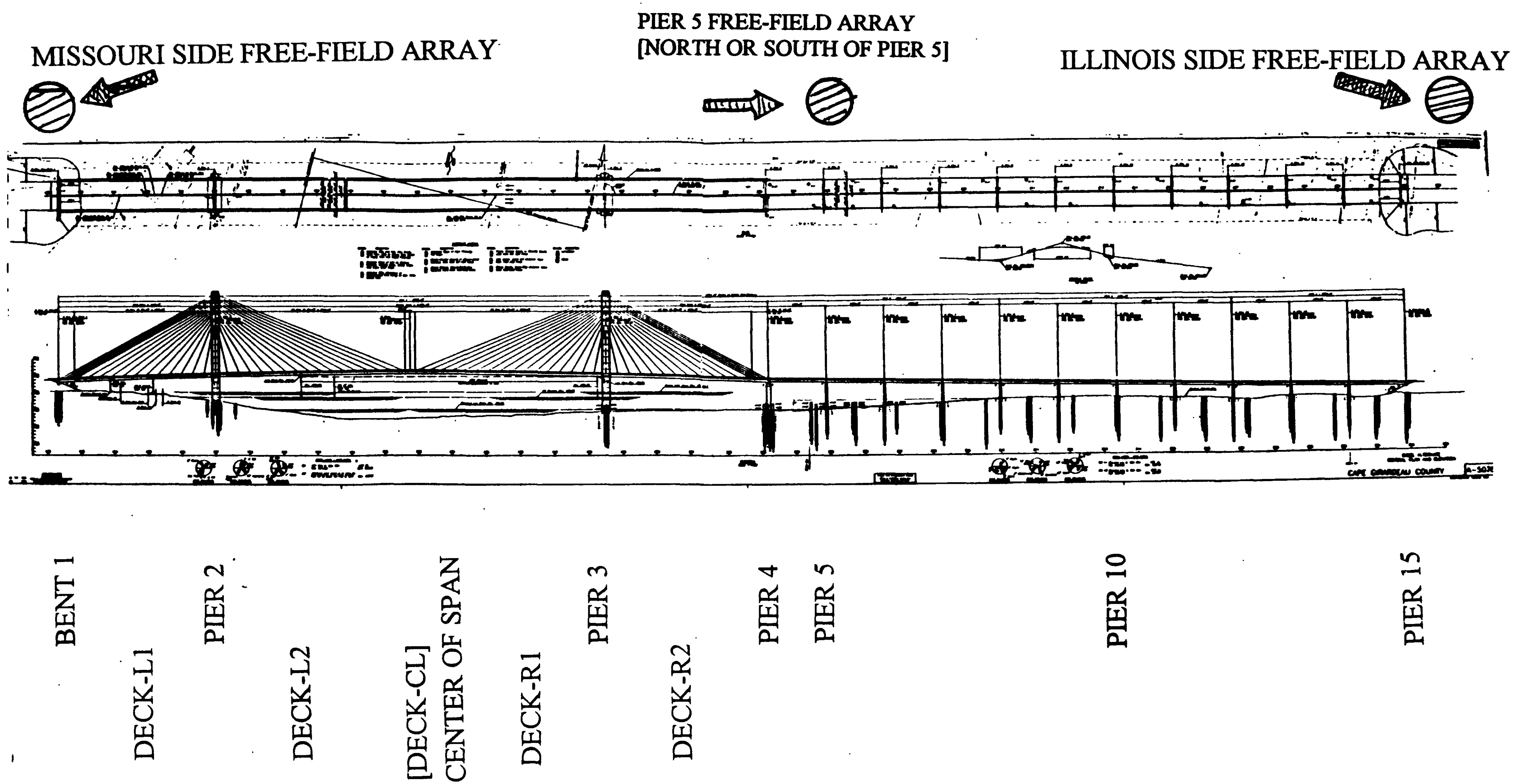
1. Each one of the downholes at East Free-Field, West Free-Field and at Pier 5 should be P-S Suspension Logged.

2. Exact location of the intermediate downhole accelerograph will be determined folowing the observations of the P-S suspension log of the lower (rock) downhole.

3. It is very likely that two separate boreholes will have to be drilled and cased at each of the East, West and Pier 5 locations to deploy two downholes, one each at a different depth. Deployment of two downholes in the same borehole is difficult.

TABLE 2. APPROXIMATE HARDWARE COST

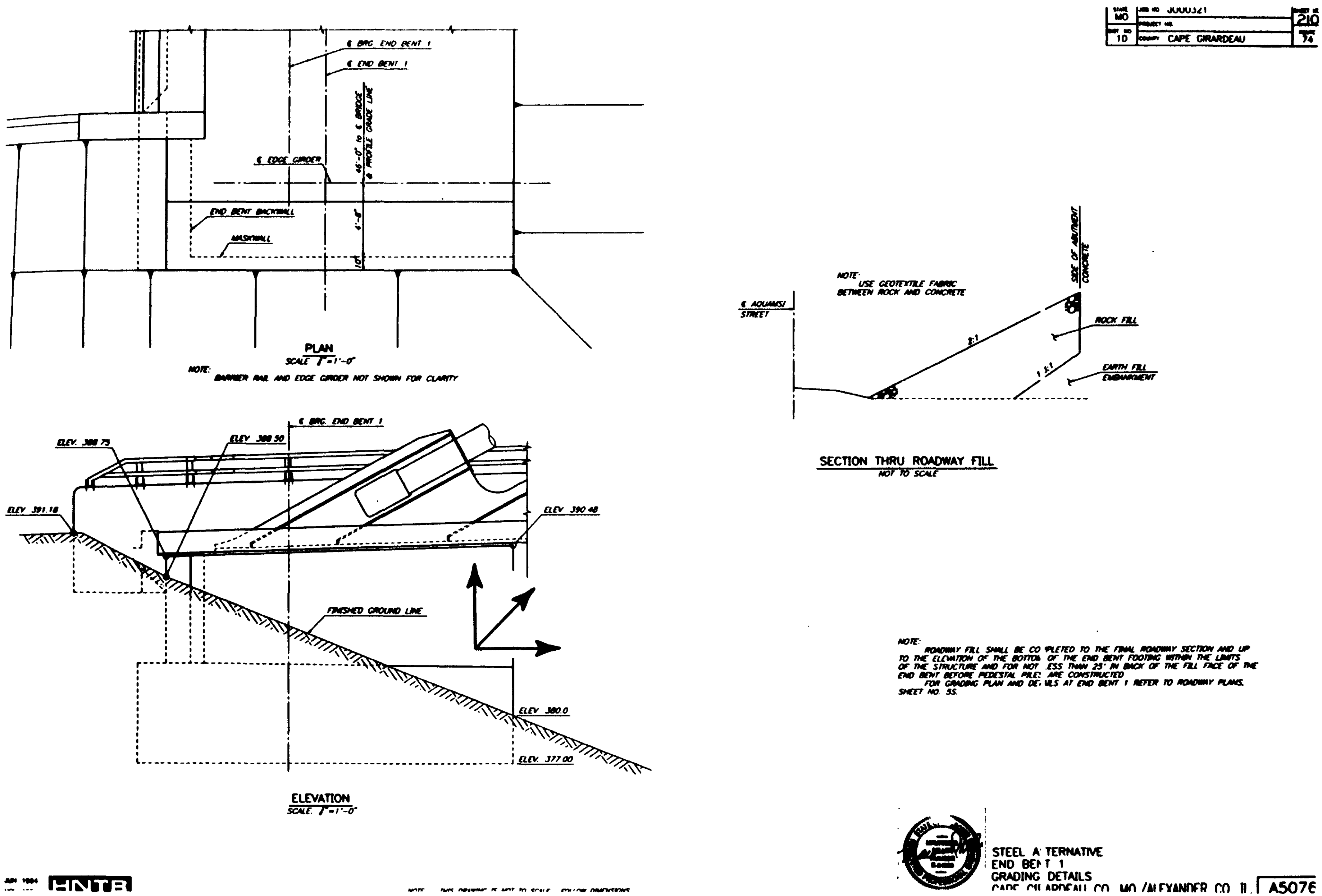
SENSOR TYPE	CHAN./UNIT	QUANTITY	CHANNELS	UNIT	TOTAL	COMMENTS
				(k)	(k)	
FBA-11	1	14	14	$ 1.00	$ 14.00	
FBA-22	2	18	36	$ 2.00	$ 36.00	
FBA-23	3	10	30	$ 3.00	$ 30.00	
FBA-23DH	3	6	18	$12.00	$ 72.00	
			98		**$ 152.00**	
RECORDERS						
Mt. Whitney	Up to 18	5		$21.00	$ 105.00	Flexible Configuration
K-2	3-12 chan.	2		$13.00	$ 26.00	Flexible Configuration
					$ 131.00	
CABLES						
Regular		8000 ft.		$ 2.00	$ 16.00	
Downhole		1500 ft.		$10.00	$ 15.00	
					$ 31.00	
CONDUITS		5000 ft		$ 3.00	**$ 15.00**	
MISCELLANEOUS					**$ 31.00**	
					$360.00	***GRAND TOTAL***



CAPE GIRARDEAU BRIDGE

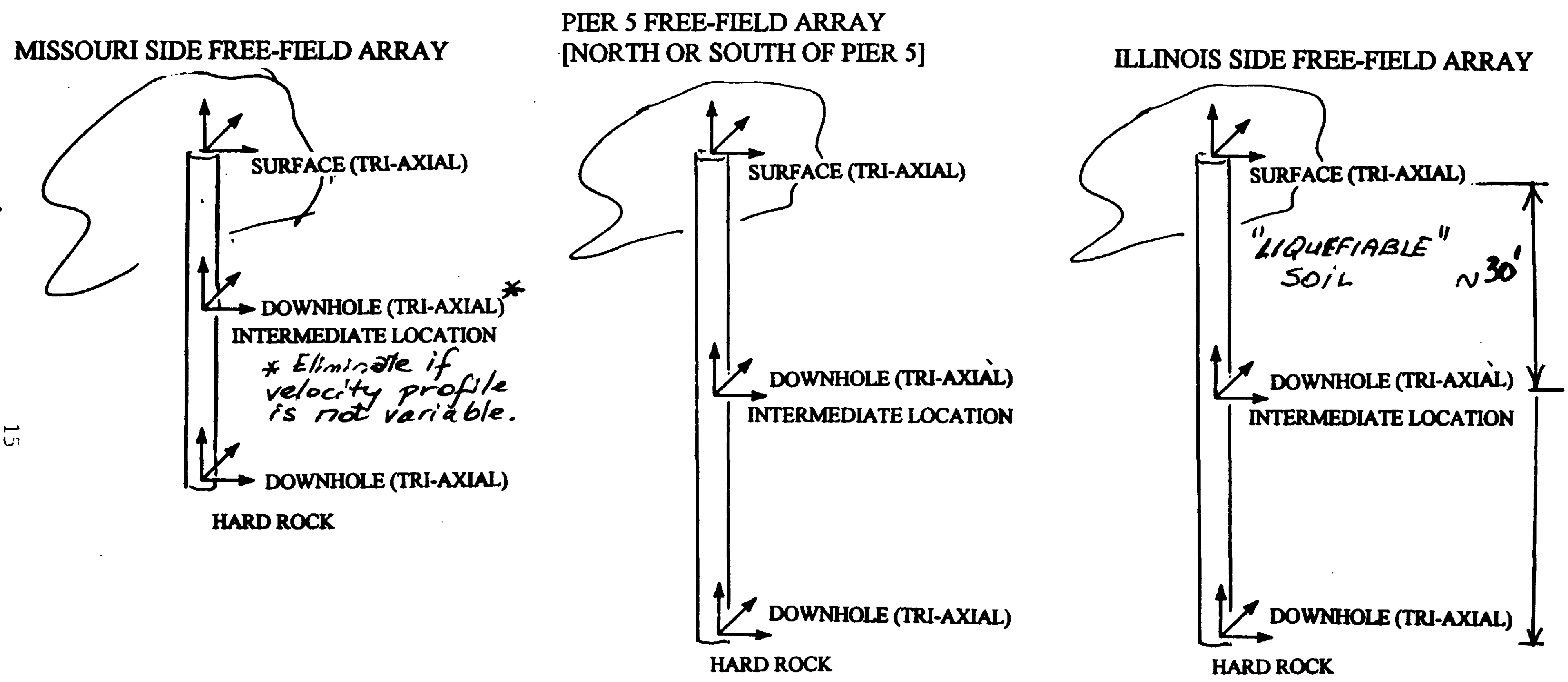
GENERAL LOCATIONS OF SEISMIC INSTRUMENTATION ALONG THE BRIDGE

FIGURE 1



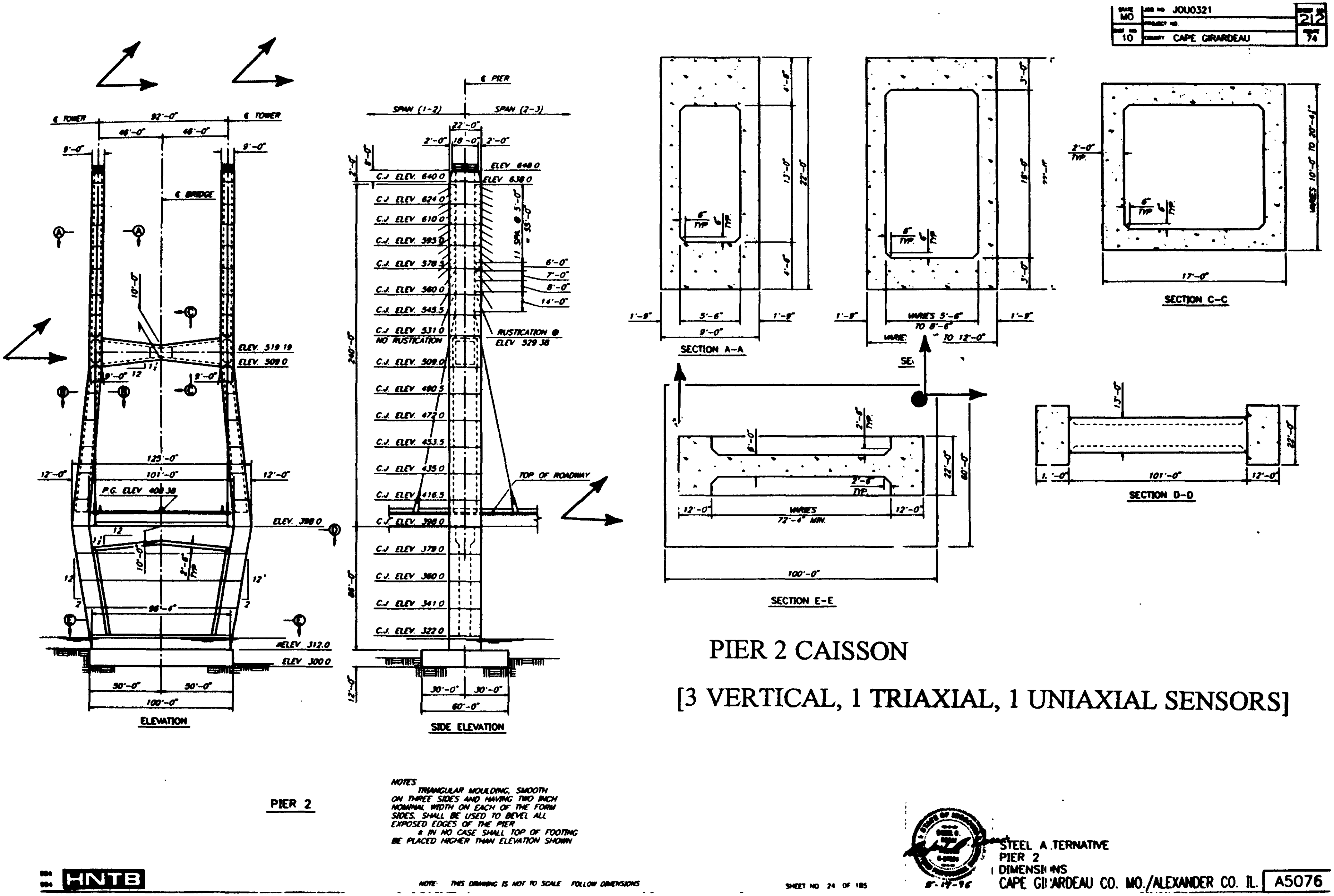
INSTRUMENTATION OF BENT 1

FIGURE 2



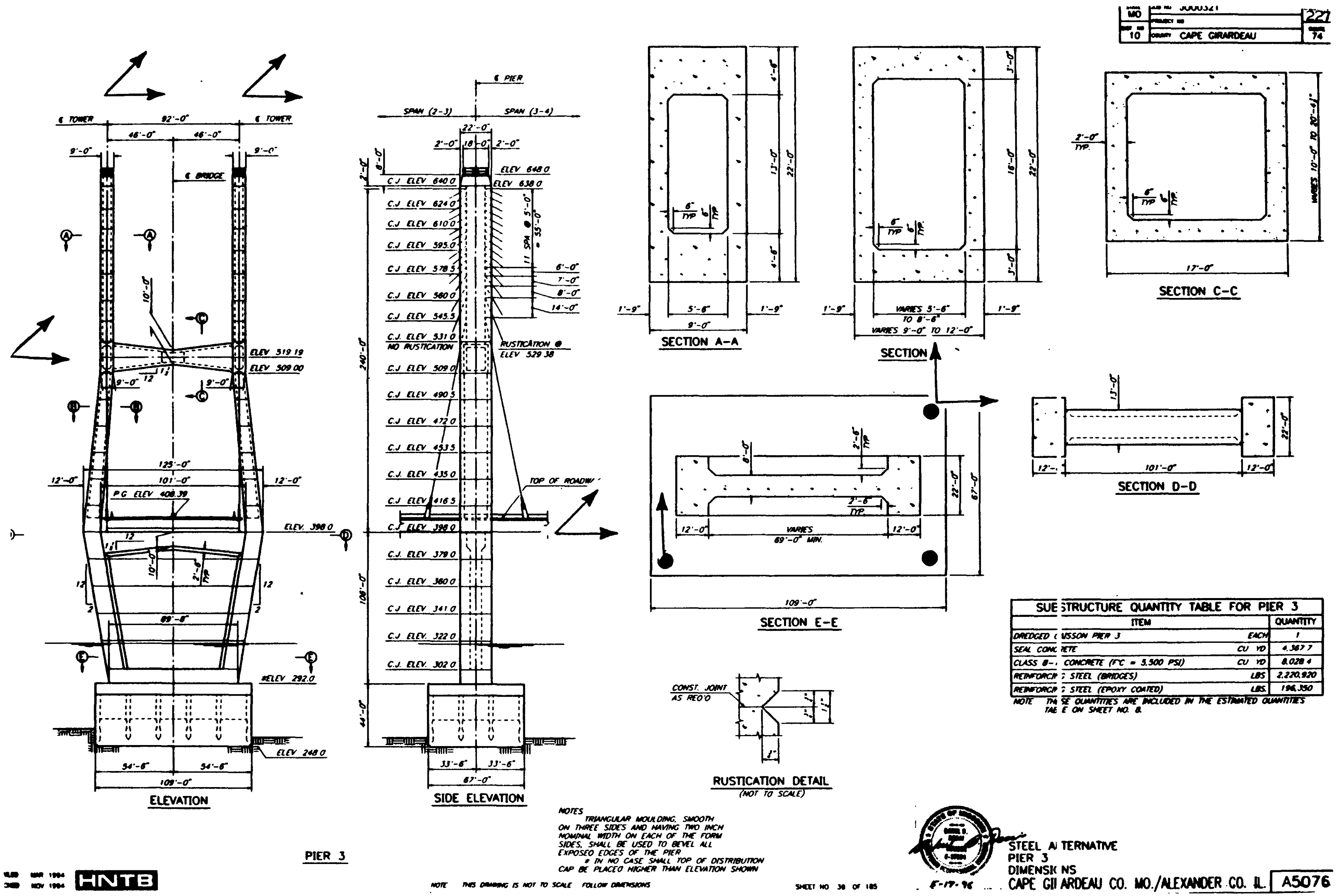
FREE-FIELD ARRAYS

FIGURE 3



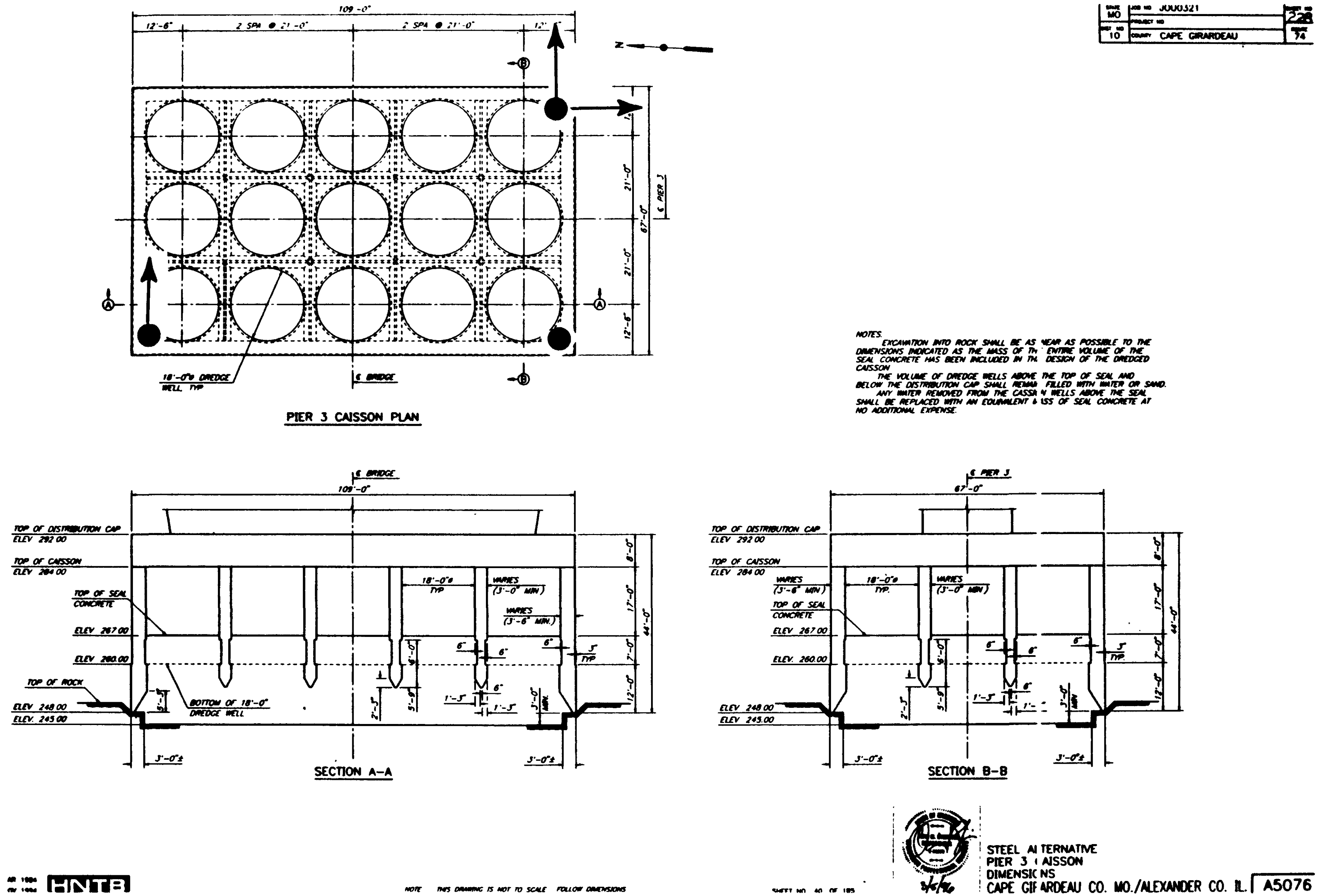
INSTRUMENTATION OF PIER 2

FIGURE 4



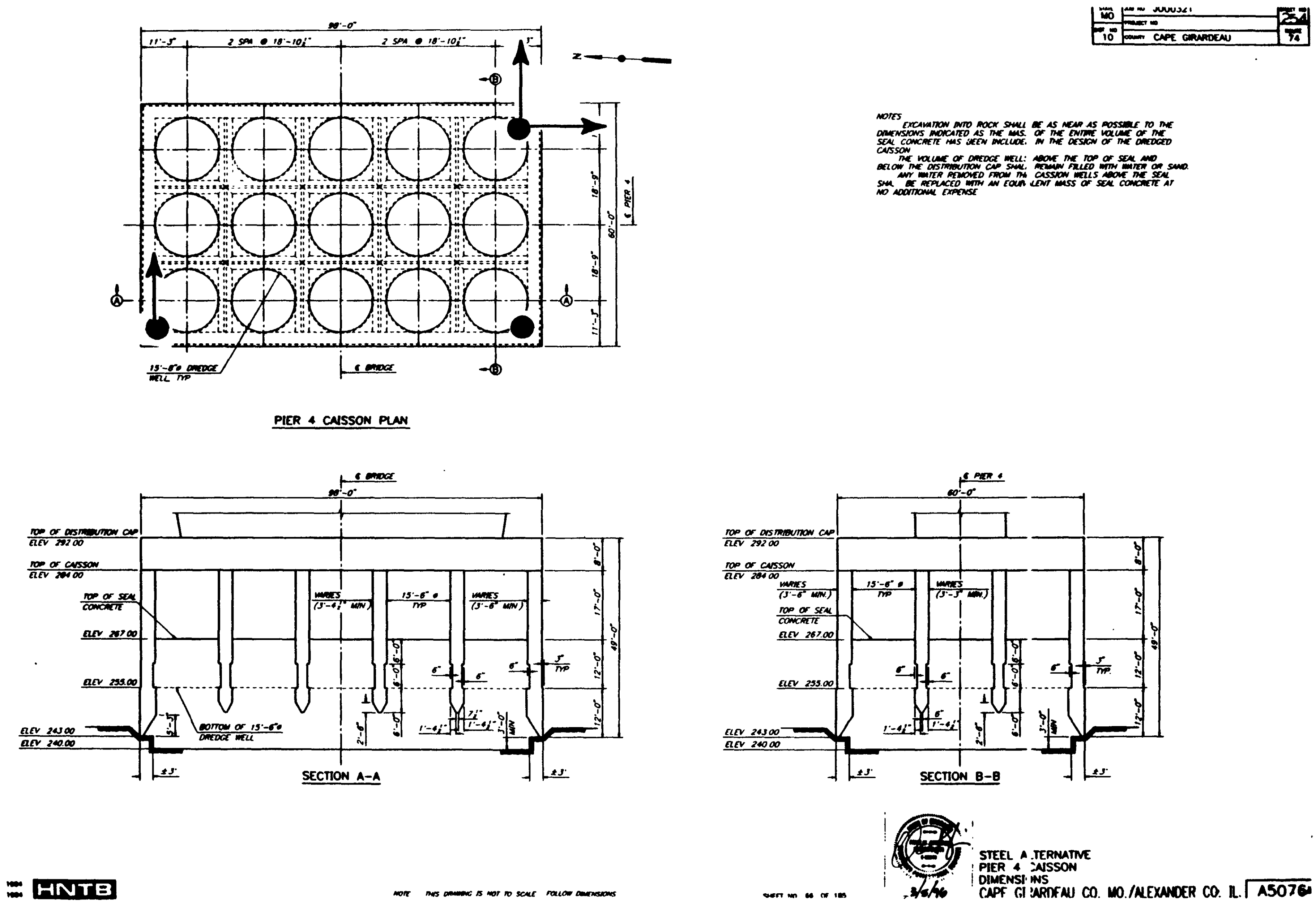
INSTRUMENTATION OF PIER 3

FIGURE 5



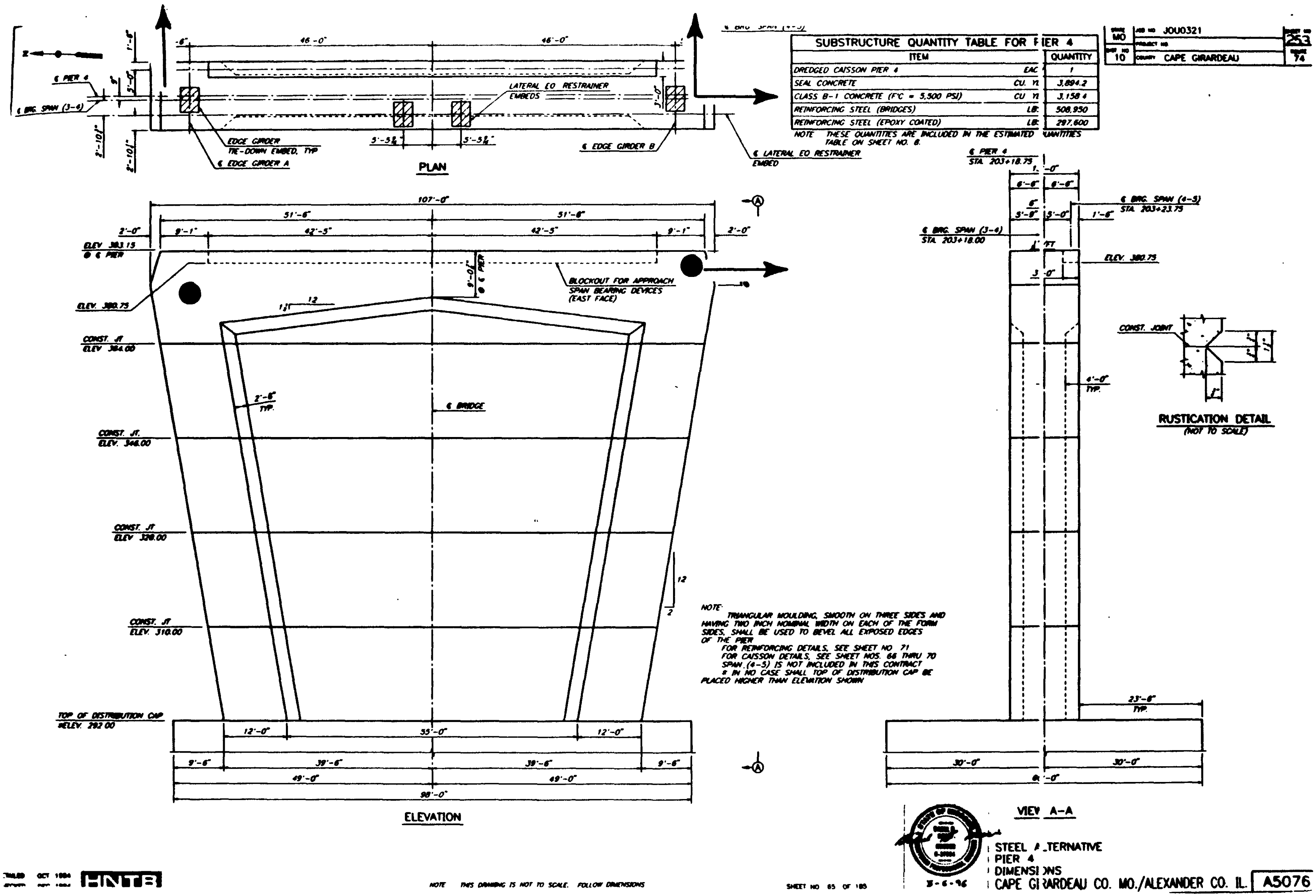
PIER 3 CAISSON [3 VERTICAL, 1 TRIAXIAL, 1 UNIAXIAL SENSORS]

FIGURE 6



PIER 4 CAISSON [3 VERTICAL, 1 TRIAXIAL, 1 UNIAXIAL SENSORS]

FIGURE 7



INSTRUMENTATION OF PIER 4

FIGURE 3

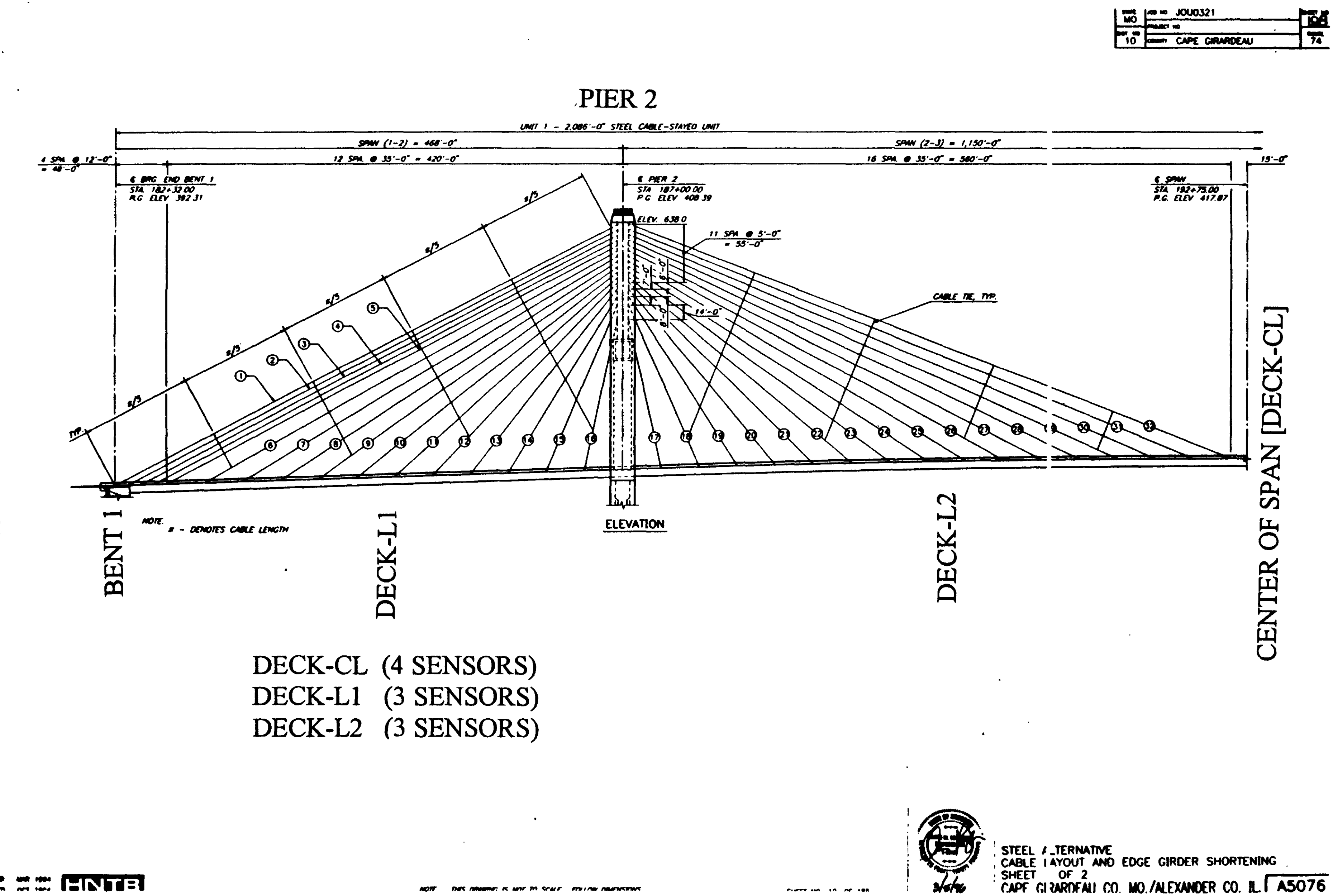
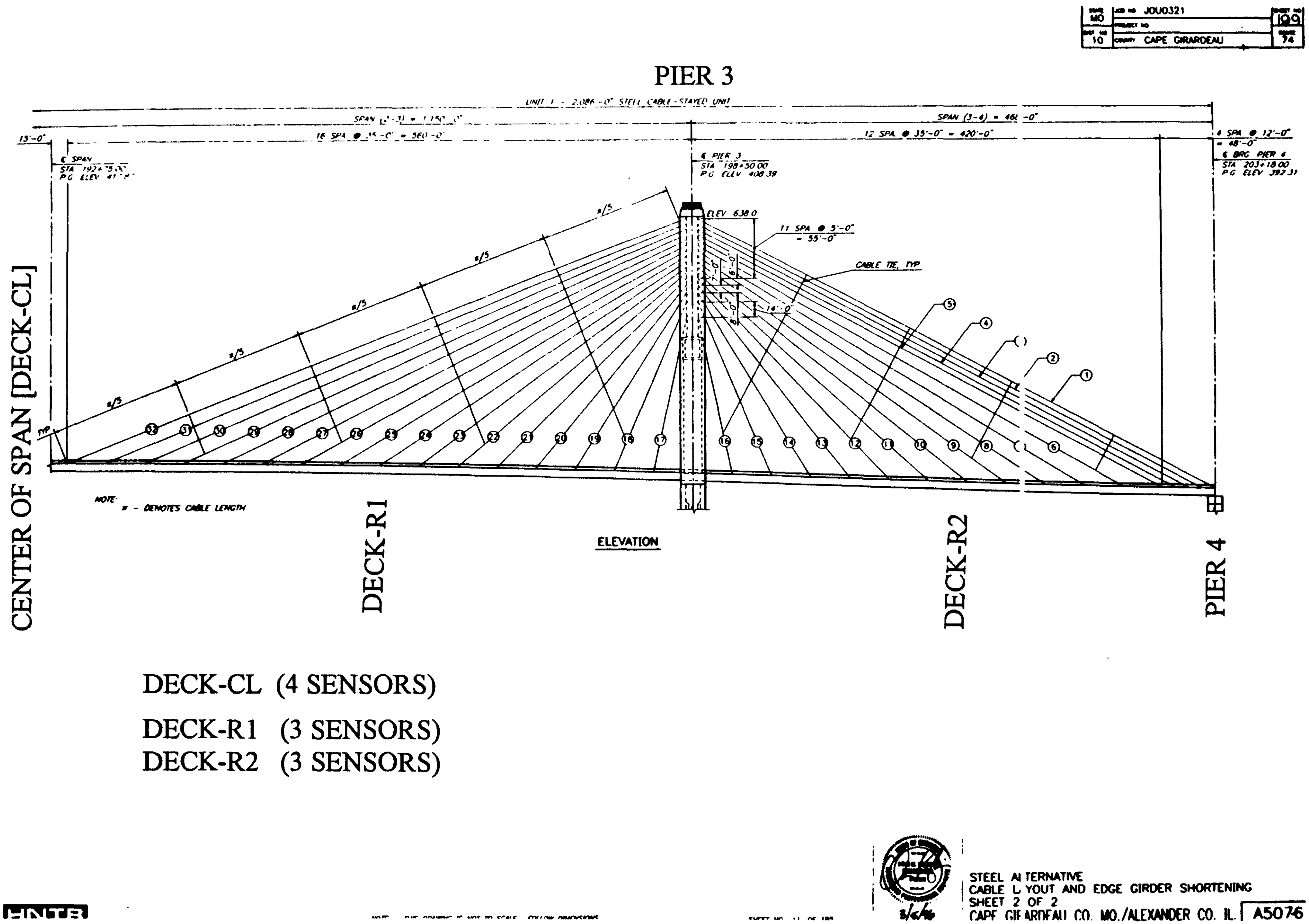

PIER 2
UNIT 1 - 2,086'-0" STEEL CABLE-STAYED UNIT
SPAN (1-2) = 468'-0"
SPAN (2-3) = 1,150'-0"
4 SPA. @ 12'-0" = 48'-0"
12 SPA. @ 35'-0" = 420'-0"
16 SPA. @ 35'-0" = 560'-0"
15'-0"
℄ BRG. END BENT 1
STA. 182+32.00
P.G. ELEV. 392.31
℄ PIER 2
STA. 187+00.00
P.G. ELEV. 408.39
℄ SPAN
STA. 192+75.00
P.G. ELEV. 417.87
ELEV. 638.0
11 SPA. @ 5'-0" = 55'-0"
14'-0"
CABLE TIE, TYP.
ELEVATION
NOTE: # - DENOTES CABLE LENGTH
BENT 1
DECK-L1
DECK-L2
CENTER OF SPAN [DECK-CL]
DECK-CL (4 SENSORS)
DECK-L1 (3 SENSORS)
DECK-L2 (3 SENSORS)
JOU0321
CAPE GIRARDEAU
HNTB
STEEL ALTERNATIVE
CABLE LAYOUT AND EDGE GIRDER SHORTENING
SHEET OF 2
CAPE GIRARDEAU CO. MO./ALEXANDER CO. IL.
A5076

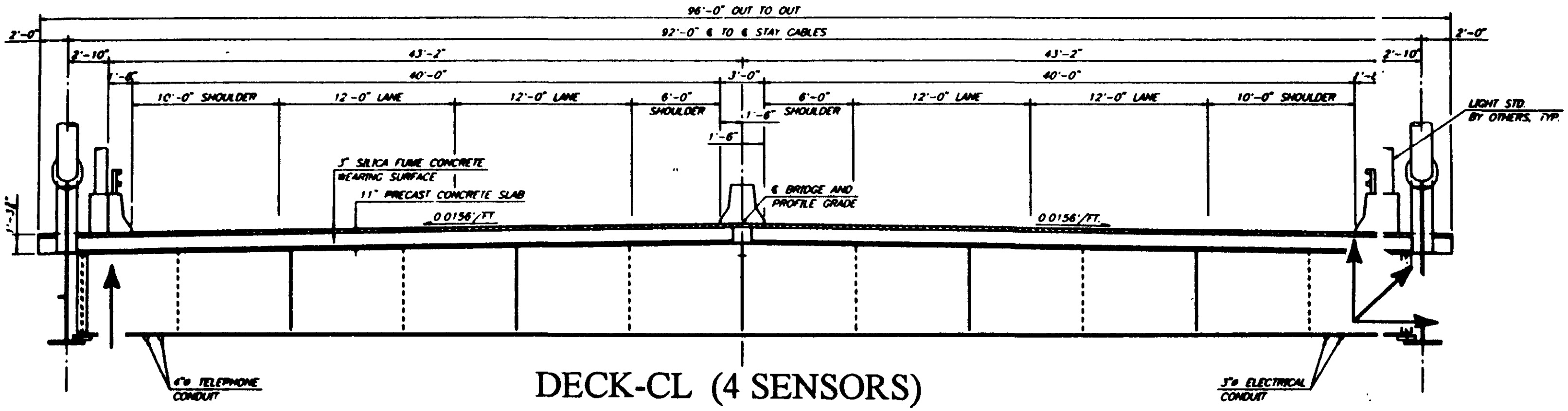
FIGURE 9



PIER 3
UNIT 1 - 2,086'-0" STEEL CABLE-STAYED UNIT
SPAN (3-4) = 468'-0"
12 SPA. @ 35'-0" = 420'-0"
4 SPA @ 12'-0" = 48'-0"
℄ BRG. PIER 4
STA 203+18.00
PG ELEV 392.31
℄ PIER 3
STA 198+50.00
PG ELEV 408.39
15'-0"
℄ SPAN
ELEV 638.0
11 SPA @ 5'-0" = 55'-0"
CABLE TIE, TYP
14'-0"
TYP
NOTE: s - DENOTES CABLE LENGTH
ELEVATION
CENTER OF SPAN [DECK-CL]
DECK-R1
DECK-R2
PIER 4
DECK-CL (4 SENSORS)
DECK-R1 (3 SENSORS)
DECK-R2 (3 SENSORS)
MO
JOU0321
10
CAPE GIRARDEAU
199
74
STEEL ALTERNATIVE
CABLE LAYOUT AND EDGE GIRDER SHORTENING
SHEET 2 OF 2
CAPE GIRARDEAU CO. MO./ALEXANDER CO. IL.
A5076

FIGURE 10

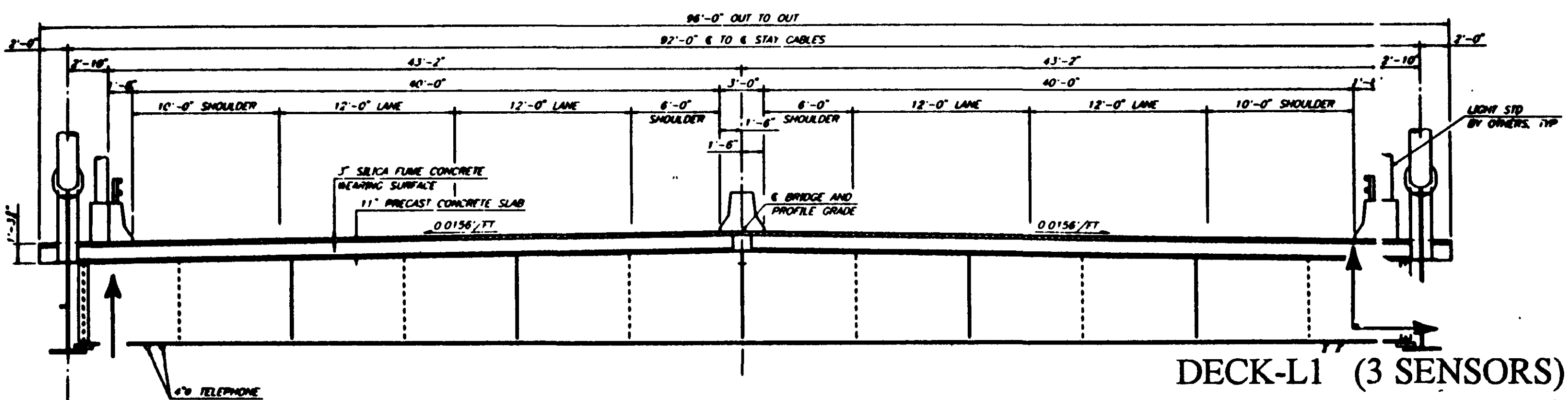
INSTRUMENTATION FOR CENTER OF SPAN [DECK-CL]



DECK-CL (4 SENSORS)

TYPICAL SECTION

INSTRUMENTATION FOR DECK LOCATIONS L1, L2, R1 and R2



TYPICAL SECTION

DECK-L1 (3 SENSORS)
DECK-L2 (3 SENSORS)
DECK-R1 (3 SENSORS)
DECK-R2 (3 SENSORS)

FIGURE 11