CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

DESIGN AND FABRICATION
PROJECTS
AND
FOUNDATION ANALYSIS

A thesis submitted in partial satisfaction of the requirements for the degree of Master of Science in

ENGINEERING

By
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Title Page</th>
<th>i</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approval Page</td>
<td>ii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>iv</td>
</tr>
<tr>
<td>Abstract</td>
<td>v</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Chapter 1: Underwater Communication Junction Box</td>
<td>3</td>
</tr>
<tr>
<td>Chapter 2: Weapon Retrieval Boat Deployment Chute</td>
<td>16</td>
</tr>
<tr>
<td>Chapter 3: Foundation Analysis</td>
<td>28</td>
</tr>
<tr>
<td>Bibliography</td>
<td>45</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Hydrophone Communication Network</td>
<td>5</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Top View of the Junction Box</td>
<td>7</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Single Quad Cable Connections</td>
<td>8</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Twelve Quad Cable Connector</td>
<td>9</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Cross Section of a Single Quad Armored Communication Cable</td>
<td>12</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Sealing and Mechanical Connection for a Single Quad Communication Cable</td>
<td>13</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Operation of the Deployment Chute</td>
<td>17</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Overview of the Deployment Chute</td>
<td>19</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Tapered Roller</td>
<td>20</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Head Roller</td>
<td>21</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Belt Tension Mechanism</td>
<td>22</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Roller Assembly</td>
<td>23</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Diagram of the Deployment Chute</td>
<td>25</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Cross Section of the Roller Assembly</td>
<td>27</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Diagram of the Cine-Sextant</td>
<td>29</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Load Diagram</td>
<td>35</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Cine-Sextant Foundation</td>
<td>36</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Load, Shear, and Moment Diagrams</td>
<td>37</td>
</tr>
</tbody>
</table>
ABSTRACT

Design and Fabrication Projects

and

Foundation Analysis

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This project report covers three independent tasks. A unique underwater communication junction box to be used as an integral part of the Midway Impact Location System was designed, fabricated, and installed. A continuous roller deployment/recovery device was designed and fabricated for use on the Weapon Retrieval Boat to aid in the deployment and retrieval of sensitive underwater test equipment. Finally, a procedure to analyze a tracking mount foundation was defined and illustrated by applying the method to the existing Cine-Sextant foundation.
INTRODUCTION

Three different tasks were included in the project assignment. The first two tasks were in the area of mechanical design and fabrication. The final task was a foundation analysis for an optical tracking mount.

The design and fabrication of an underwater communication junction box is described in Chapter 1. The junction box is designed to connect five separate one quad armored communication cables to a single twelve quad armored communication cable. It includes a unique characteristic by which five additional single quad armored cables may be spliced to the twelve quad cable after the junction box has been installed on the ocean floor.

Chapter 2 describes the design and fabrication of a deployment chute to be used on the stern of the WRB (Weapon Retrieval Boat). Its purpose was to aid in the retrieval and deployment of sensitive underwater test equipment at PMRF (Pacific Missile Range Facility) at Barking Sands, Hawaii. The device features a continuous free roller belt operation suitable for operating in a saltwater environment.

The final Chapter defines a procedure to analyze a foundation for an optical tracking mount. The analysis takes into consideration the static and dynamic forces as they relate to the tracking accuracy of the instrument. The procedure is illustrated by applying it to
the existing foundation for the Cine-Sextant. The Cine-Sextant is a high precision optical automatic tracking instrument used for tracking high acceleration targets at the Pacific Missile Test Center (PMTC). It requires a rigid foundation to minimize deflections which could introduce tracking errors.
CHAPTER 1

UNDERWATER COMMUNICATION JUNCTION BOX

At Midway Island in the South Pacific Ocean the United States Navy has an underwater hydrophone Missile Impact Location System (MILS). Its purpose is to use a network of underwater hydrophones to detect the impact location of a missile in the ocean. The acoustical signal of the impact is detected by the hydrophones and an electrical signal is transmitted via five cables along the bottom of the ocean to the surface of Midway Island where the data can be reduced.

A problem developed in the system and not all of the signals were being received from the hydrophones. It was hypothesized that some of the conductors within the armored cables were broken and it was believed the breaks occurred close to shore due to the surf action.

To restore the detection system, a solution was proposed which would not only repair the damage but also increase the potential number of hydrophones that could be used. The proposed solution was to replace the first mile of all of the five cables with a single larger cable. The five single cables each contain four electrical conductors and are called single quad cables. The new larger cable contains forty-eight electrical conductors and is called a twelve quad cable. The new twelve quad cable would be laid from Midway Island along the ocean floor for approximately one mile, at which
point it would be joined to the existing five single quad cables. The task assigned was to design and fabricate an underwater junction box suitable for splicing the twelve quad cable to the existing five single quad cables (see figure 1). In addition to providing a junction box capable of joining the five existing hydrophone cables, it was desired to provide a means by which five additional quads from the twelve quad cable could be joined to five new single quad cables, thereby increasing the total number of hydrophones that could potentially be used in the system.

In the process of designing the junction box there were six primary requirements.

1. The junction box must be sealed to prevent intrusion of seawater, thereby protecting the splices from corrosion.
2. The junction box must be designed so that five additional armored single quad hydrophone cables may be spliced to the twelve quad cable. This operation must be performed by a diver on the ocean floor. When completed the junction box must remain sealed from the seawater.
3. The connection between the armored cables and the junction box must be mechanically sound to prevent damage to the splices if the cables are placed in tension.
4. The junction box must be secured to the ocean floor.
5. There must be access to the box so a diver can inspect, service, and add cables without great difficulty.
6. The entire junction box must be resistant to corrosion.

The remainder of this Chapter will describe the design pro-
MIDWAY ISLAND, JUNCTION BOX TWELVE QUAD ARMORED CABLE HYDROPHONE COMMUNICATION NETWORK

FIGURE 1
cess and an evaluation of the junction box after it was put into operation. The completed junction box is depicted in figures 2, 3, and 4.

In approaching the problem of satisfying the design requirements, it was recognized that the most difficult single requirement to meet would be number 2. Therefore it was felt this would be the most important aspect to consider before proceeding. It appeared that the only way to add additional cables to the junction box would be to open it up, thus allowing the seawater into the box. This would corrode the splice. Therefore the problem was to find a way to remove the seawater after the box had opened. The first alternative considered was to pump out the seawater. This would be physically awkward. It would create a partial vacuum inside the box and not get all of the seawater out, it was rejected.

Another alternative would be to fill the entire box with an insulating solid potting compound. When it was desired to add the new hydrophone cables a diver would cut away the excess potting compound, splice in the new conductors and refill the box with new potting compound. The potting material would have to be heavier than seawater to displace it and it would also have to cure underwater. This seemed feasible, however it would be difficult to accomplish underwater. Also, no potting compound with the required characteristics was known. The idea of using the potting compound to displace the seawater led to the final solution. Rather than using a solid potting compound it was decided to use a liquid material. The liquid would have to be a good dielectric and be denser than seawater. The
SINGLE QUAD CABLE CONNECTIONS

FIGURE 3
next step was to find a product meeting these criteria. A material called fluorinert FC-77 was found which at $77^\circ$ F has a dielectric strength of 45 KV/.01 inches and a density of 111 pounds per cubic foot. In addition it is chemically inert.

The splicing operation will be done on a ship at Midway Island. The box will be filled with fluorinert and the seals secured. The entire box and connected cables will be lowered and secured to the ocean floor. When the additional hydrophones are needed the junction box will be opened up by a diver and the appropriate splices made. On completion the diver will refill the box with a new supply of fluorinert. Since the fluorinert is heavier than seawater, it will displace the seawater out of the top of the box. The lid will then be secured and the entire assembly will once again be protected from saltwater intrusion.

The next problem undertaken was that of getting the conductors inside the box without letting the seawater in. The first alternative considered was to use a rubber plug with a tapered hole in the center, through which a single conductor would fit through. The entire plug which would also be tapered, would be forced into a hole thereby sealing the conductor. Due to the large number of conductors involved; ninety eight in total, it was realized that a separate sealing plug for each conductor would require an excessive amount of space. An improvement to this idea was to provide four tapered holes in each sealing plug for the single quad cables and forty eight tapered holes in the plug for the twelve quad cable. Silicon was selected as a appropriate material for the plugs. It was necessary to make two
aluminum molds to manufacture the tapered plugs. It was later decided that pressing the tapered plug into the hole by hand did not provide a sufficiently good seal, so threaded retainers were designed and fabricated which would force the plug securely into the hole and prevent the plug from being dislodged by accident. Figure 5 shows a cross section of a typical single quad cable and Figure 6 depicts how the silicon plug seals the box.

To provide a mechanically sound connection between the armored cable and the junction box it was necessary to attach the armor of the cable to the box. One method to attach the armor would be by welding. An alternative would be clamping, which seemed to be more feasible. The method used was to provide a circle of threaded rods around each entry hole, over which a large retaining ring would clamp the armor of the cable between the box and the retaining ring. In the preliminary design the threaded rods were 1/4 inch diameter but later were changed to 1/2 inch diameter.

Figure 6 shows the armor flared out and secured to the junction box by the retaining ring.

Several different shapes for the junction box were considered. The objective was to minimize the volume because of the high expense of the fluorinert and to maximize the ease with which the cables could be spliced. The resulting design met this criteria while also keeping the shape of the box geometrically simple. This minimized the cost of both drafting and manufacture. The inside dimensions were 13.00 by 32.00 by 12.00 inches deep, which is a volume of 2.89 cubic feet. If the entire box was filled with fluorinert, it would
CROSS SECTION OF A SINGLE QUAD ARMORED COMMUNICATION CABLE

FIGURE 5
SEALING AND MECHANICAL CONNECTION FOR A SINGLE QUAD COMMUNICATION CABLE

FIGURE 6
require 320.67 pounds at $9.50 per pound which would be $3046. In an effort to minimize this cost it was concluded that any excess volume should be filled with a less expensive material. At first various configurations were considered to mold silicon into various parts of the box. This idea was abandoned for a better alternative. By filling the box with glass spheres such as marbles after the splices were completed a significant amount of the void could be reduced without interfering with the room necessary for coiling the spliced conductors into the box. By using this technique the volume of fluorinert was reduced to about 1.2 cubic feet or a cost of $1205.

To provide access to the box, a lid was required. A clear plate of 3/4 inch thick plexiglass would allow a diver to inspect the contents of the box without removing the lid. An external flange was used to support the lid so as not to interfere with access to the interior. Since the interior would be filled with liquid, pressure was not considered in the selection of the lid. Two port holes were put in the lid so that fluorinert could be added to the box without removing the lid. The plug for the port hole was made of delrin and utilized a neoprene o-ring boss for sealing. The length of the 5/8 inch threaded plug governed the thickness of the lid. To seal the plexiglass lid it was desired to have a seal that a diver could easily install underwater. Parker Seal Company custom manufactures metal gaskets with neoprene molded to each side. Such a seal would be ideal but the cost to manufacture one seal was quoted at $4000. The selected alternative was to use a sheet of 1/4 inch thick neoprene cut to the size of the top bearing flange.
To secure the junction box to the ocean floor it was decided to use four orange peel rock bolts. These devices were designed by R. Brackett specifically for underwater use and are made of titanium. A hole is drilled into the ocean floor and the rock bolt is inserted. By tightening a nut, the bolt expands to fill the hole.

Finally the problem of corrosion was solved by using an external cathodic protection device. The idea and design is credited to Harry Lee in Electronic Devices. A power source on Midway Island supplied a current to the junction by using two quads in the twelve quad cable. By using this method of corrosion control it was possible to use mild steel for the construction of the junction box. All of the welds were inspected by X-ray. Then the box was sandblasted, cadmium plated, and painted with epoxy white paint.

An evaluation of the installation revealed two areas where the design could have been improved. First, the installers felt that there was a weak point where the armored cables were flared out around the receiving tube. As a result they installed some 'L' shaped brackets to reinforce this area and then wrapped the cable and supporting 'L's with band-it stainless steel clamps. In addition the installers recommended that a slip ring with holes to match each strand of armor in the cable would have aided in the installation by slipping the ring over the receiving tube. Each strand of armor would then fit through each hole thus helping to keep the stands separated as they were clamped under the retaining ring. The junction box was put into operation in September 1975 and has been proven successful.
CHAPTER 2
WEAPON RETRIEVAL BOAT DEPLOYMENT CHUTE

At the Pacific Missile Range Facility (PMRF) at Barking Sands Kauai, Hawaii the United States Navy uses a Weapon Retrieval Boat (WRB) to deploy and retrieve sensitive underwater equipment. The Pacific Missile Test Center (PMTC) requested the Design and Fabrication Department to design and fabricate a deployment chute to be used on the WRB. Several features were requested to be included in the design.

1. A continuous roller belt suitable for protecting small instruments as they are deployed.
2. The device should be mounted on the stern deck.
3. It should be made of suitable materials to resist corrosion.
4. The deployment chute should provide a smooth transition from the deck to the ocean during deployment.
5. The deployment chute should be capable of handling a torpedo.

Figure 7 shows the operation of the deployment chute. The preliminary design investigated possible alternatives to solve the problem without going to extensive detail. Once a preliminary concept was selected more attention was given to individual components. At this stage, a cost estimate was made which itemized the cost for materials, engineering, drafting, and fabrication. During the early phase of design it was very important to consider the difficulty which would be encountered in drafting and fabrication since these two areas have significant influence on the total cost of the project. The cost
INSTRUMENTATION OR TORPEDO

DEPLOYMENT CHUTE

WEAPON RETRIEVAL BOAT

OPERATION OF THE DEPLOYMENT CHUTE

FIGURE 7
of material is generally the least significant factor.

The next step was to prepare a preliminary layout. This integrates the subcomponents into the total system. The layout was modified several times, until all the features of the design were integrated. This was done concurrently with the selection of materials and off-the-shelf products to be used in the design. When the layout was finalized the material was ordered and a draftsman prepared formal drawings. During this stage many details of the design were resolved. The next step was to issue the drawing package to the Shops Division for fabrication. Figures 8, 9, 10, 11, and 12 depict the deployment chute near the end of fabrication.

The most important requirements governing the initial design was that a continuous belt was requested and the assembly must be large enough to handle a torpedo. A typical torpedo is 20 inches in diameter and weighs 6000 pounds. A continuous belt requires some type of rollers to support it. It was also desirable to have rollers which cradled the instrument or torpedo to keep it in the contour of the deployment chute. To accomplish this it was considered to use three straight rollers end to end, the outer two elevated about 20 degrees and the center roller flat, thus providing a cradle. This led to complications because considerable space was required for bearing supports. To simplify the design it was considered to use two straight rollers placed in a Vee shape. This would require four bearings instead of six. This was an improvement but still created space complications. The final concept was to use a tapered roller which would provide uniform support over the entire width and also cradle the
OVERVIEW OF THE DEPLOYMENT CHUTE

FIGURE 8
ROLLER ASSEMBLY

FIGURE 12
instrument, (Figure 13). Using tapered rollers simplified the bearing and frame work requirements but required extensive lathe work. In addition to the tapered rollers it was desired to have an end roller (or tail roller) with extra high sides. A continuous belt would ride over the two tapered rollers, around the tail roller, over two return rollers, and finally around a head roller, thus providing a smooth transition over the deck.

With general concept of the design established the remainder of the design effort concentrated on the individual components and their integration into a reliable functional device.

Early in the design process it was decided to use 6061 aluminum for the frame and rollers. Because it is light, corrosion resistant, and compatible with the material used in the WRB. The frame was made of quarter inch stock. Each of the two tapered rollers were machined from solid stock and were 25 inches long with a minimum root diameter of 2.00 inches and a maximum diameter of 6.00 inches. The tail roller was made of 10 inch diameter quarter inch wall tubing with 30 inch diameter tapered side walls. The two return rollers were made from 2 inch diameter quarter inch wall material. The head roller is a 6 inch diameter straight roller mounted on an adjustable springloaded mechanism to maintain tension in the belt. The spring mechanism (Figures 10 and 11) utilized a stainless steel compression spring inside of a telescoping tube.

A very important consideration was the necessity of providing reliable, compact, corrosion resistant bearings for each roller. After considering various stainless steel bearings, a non-metallic
DIAGRAM OF THE DEPLOYMENT CHUTE

FIGURE 13
bearing was selected. These bearings are made of a combination of teflon and delrin. For the expected loading they will provide outstanding service. The bearing housing that was designed, features an extremely easy method to replace bearings and install the roller assemblies. A typical bearing assembly is illustrated in Figure 14.

The material selected for the roller belt was 3/16 inch neoprene, however this proved to be inadequate because it failed to remain centered on the rollers. An alternative material made of heavy canvas was substituted.

Total cost of the project was $26,197.
CROSS SECTION OF THE ROLLER ASSEMBLY

FIGURE 14
CHAPTER 3
FOUNDATION ANALYSIS

At the Pacific Missile Test Center (PMTC) optical instruments are used to track high acceleration missiles and targets. There are numerous errors in these instruments that degrade their accuracy. For this reason an effort is made to minimize the errors in the tracking operation. One significant source of error is the foundation on which the tracking mount is placed. If the foundation does not provide a sufficiently rigid platform from which to track, the data will be affected. The objective of this project is to develop a procedure to analyze the foundation of a tracking mount, taking into consideration static and dynamic forces as they relate to the tracking accuracy.

The procedure will be applied to an existing foundation which is used for the Cine-Sextant. The foundation is a reinforced concrete slab, 10 feet in diameter and 2 feet thick. The Cine-Sextant is illustrated in figure 15.

The procedure to analyze a foundation for a tracking instrument can be summarized in four steps.

1) Establish a maximum allowable dynamic deflection for the foundation that will not significantly affect the overall tracking accuracy.

2) Check the foundation to insure that it is sufficient to resist the dead weight and overturning moments created by the
Diagram of the Cine-Sextant

Figure 15
tracking operation.

3) Calculate the deflection of the foundation due to the dynamic loading of the optical instrument as it tracks a target and compare it to the allowable deflection.

4) Investigate the response of the foundation to environmental ground vibrations.

The method to accomplish each of these four steps will be illustrated in the remainder of the Chapter.
STEP 1)

The ideal would be to limit the deflection of the foundation to zero. By doing this there would be no new errors introduced into the tracking system. This would require an infinitely rigid foundation which would be economically impractical. The objective is to limit the deflection to some value which is characteristic of the inherent errors existing in the tracking instrument.

A traditional goal is to limit any single error to one tenth of the total composite error. The total composite error is due to such factors as the static and dynamic bending deflections of the tracking mount, bearing runout, collimation, and misleveling. For the Cine-Sextant the total composite tracking error is approximately 36 arc-seconds. Therefore a good maximum allowable foundation deflection would be 3.6 arc-seconds.

As the various errors are corrected the cumulative tracking error will be reduced. Eventually it will approach the limiting value of the square root of the sum of the squares of the least significant bit of the azimuth and elevation encoders. As the total accuracy of the instrument is improved the maximum allowable foundation deflection should be reduced.
STEP 2)

To check the foundation to insure that it is sufficient to resist the dead weight and overturning moments created by the tracking mount it is necessary to define several characteristics. It is necessary to know the overturning forces and how they will be transferred to the foundation. In addition the properties of the soil underlaying the foundation must be investigated.

The Cine-Sextant weighs approximately 7000 pounds. The existing foundation is a reinforced concrete slab 10 feet in diameter and 2 feet thick. The tracking mount bears on three loading points which are equally spaced on a 30 inch radius. In addition the Cine-Sextant is provided with a 162 inch hemi-spherical dome which bears on a slab which is external to the main foundation. This dome protects the tracking mount from the wind. Therefore the foundation does not have to support the overturning forces caused by the wind.

As the tracking mount tracks the target its velocities and accelerations generate over-turning forces. To calculate their magnitude it is necessary to establish the masses which will be moving, the eccentricity of those masses from the axis and the foundation, the angular velocity, and the angular acceleration. This information has been summarized below.

\[ W_1 = \text{weight of the instrumentation} = 1000 \text{ lb} \]
\[ W_2 = \text{weight of the forward mounting platform} = 105 \text{ lb} \]
\[ W_3 = \text{weight of the rear mounting platform} = 95 \text{ lb} \]
\[ r_1 = \text{eccentricity of the instrumentation center of gravity} = 24 \text{ in} \]
\[ r_2^2 = \text{eccentricity of the forward platform center of gravity} \]
\[ = 15 \text{ in} \]
\[ r_3^2 = \text{eccentricity of the rear platform center of gravity} \]
\[ = 13.5 \text{ in} \]
\[ \alpha = \text{acceleration of the elevation axis} = 6 \text{ rad/sec}^2 \]
\[ \omega = \text{velocity of the elevation axis} = 1.57 \text{ rad/sec} \]
\[ h = \text{eccentricity of the resultant horizontal forces about the base of the foundation} = 110 \text{ in} \]
\[ a = \text{Total acceleration} = a_n + a_t \]
\[ a_n = \text{normal acceleration} = r\alpha^2 \text{ in/sec}^2 \]
\[ a_t = \text{tangential acceleration} = r\omega \text{ in/sec}^2 \]
\[ m = \text{mass} = W/g \text{ Slug} \]
\[ F = \text{resultant force due to rotation} = ma \text{ lb} \]
\[ M = \text{moment in-lb} \]
\[ r = \text{radius of foundation} \]

The following computation illustrate how to obtain the overturning moment (Figure 16).

It is necessary to determine the required thickness for the slab. A flat circular slab is a very complex structure and it is extremely difficult to determine the magnitude and location of the stresses, particularly with the loading as defined in this case. A simplification which will result in a conservative design was employed. Several possible simplifications were considered. One possibility would be to use a single point loaded on a circular or square section; however this was abandoned for the assumption of using two loading points on a rectangular section. This concept more realistically re-
presents the actual case. For the sake of simplicity the size of the rectangular section was chosen to be symmetrical about the loading points. Assume that two of the loading points are bearing on a rectangular area which is 30 X 116 inches (Figure 17). This is now equivalent to a rectangular footing with two loading points. The dead weight applied to each of these points is one third of the total weight or 2333 pounds. Assuming that the overturning moment acts equally through each of the two loading points this will add an additional \( M/2r = 444 \) pounds to each. The total vertical load per loading point is 2777 pounds. The conventional methods for multiple column footings can be used to solve this problem. The American Concrete Institute Code Committee has not stated specific requirements for the design of multiple column footings. Traditionally, such footings have been designed as inverted beams, using beam design criteria. Figure 18 illustrates the loaded beam and the resulting shear and moment diagrams. Using the conventional method of reinforced concrete beam design by the working stress method it was found that the required thickness for the slab to support the tracking mount was 6 inches.

The resulting bearing pressure \( q \) is the summation of the instrument weight, the dynamic loading, and the dead weight of the concrete divided by the total area.

\[
\begin{align*}
W_I &= 7000 \text{ lb} \\
F_d &= 23460 \text{ lb} \\
W_f &= 888 \text{ lb} \\
A &= 79 \text{ ft}^2 \\
q &= 400 \text{ psf}
\end{align*}
\]
\[ a_1 = 59.15 \, i + 144 \, j \, \text{in/sec}^2 \]
\[ a_2 = 36.97 \, i + 90 \, j \, \text{in/sec}^2 \]
\[ a_3 = -33.28 \, i + 81 \, j \, \text{in/sec}^2 \]

\[ F_1 = 153 \, i + 373 \, j \, \text{lb} \]
\[ F_2 = 10 \, i + 24 \, j \, \text{lb} \]
\[ F_3 = -8 \, i + 20 \, j \, \text{lb} \]

Moments about 'o'
\[
(153 + 10 - 8)(110) + (373)(24) + (24)(15) + (20)(13.5) = 26632 \, \text{in-lb}
\]
\[
= 2219 \, \text{ft-lb}
\]
CINE-SEXTANT FOUNDATION

FIGURE 17
LOAD, SHEAR, AND MOMENT DIAGRAMS

FIGURE 18
An investigation of the existing soil revealed that it consists primarily of loose and fine silty sands. The allowable bearing pressure as defined by the Uniform Building Code 1970 for this type of soil is 1500 psf. The resulting bearing pressure is within this limiting criteria.

The existing foundation is adequate to support the deadload and overturning moments.
STEP 3)

To determine the theoretical dynamic deflection in the elevation axis or rocking mode and the deflection in the azimuth axis or twisting mode, it is necessary to define numerous properties for the soil, the foundation, and the tracking mount. The following calculations for the Cine-Sextant illustrate what characteristics must be defined and how to use them to calculate the desired pitch angles.

Dynamic Soil Characteristics

The value for Poisson's ratio ($\gamma$) and Young's modulus ($E$) can be obtained from a soil analysis or can be estimated. For sandy soils Poisson's ratio is approximately 0.35 and Young's modulus is approximately 550 Kg/cm$^2$. The area of the foundation is 78.3 ft$^2$. The value of the foundation geometry coefficient ($C_s$) is 1.06.

$$u = C_u E / A^{1/2} (1 - \gamma^2)$$

$$= 1.18 \times 10^5 \text{ lb/ft}^3$$

$$C_u = \text{coefficient of the uniform modulus of compression}$$

$$C_o = \text{non-uniform modulus of compression}$$

$$= C_u K \phi C_s \text{ where } K = 1.984$$

$$= 2.21 \times 10^5 \text{ lb/ft}^3$$

$$C_\psi = \text{coefficient of elastic non-uniform shear}$$

$$= 1.50 \times 10^5 \text{ lb/ft}^3$$

Cine-Sextant Physical Properties

$$W = \text{overall weight}$$

$$= 7000 \text{ lb}$$

$$r = \text{radius of foundation}$$

$$= 5.0 \text{ ft}$$
$Z_0 =$ height of center of gravity above the foundation/soil interface

= 5.0 ft

$I_a =$ area moment of inertia about the foundation/soil interface

= 491 ft$^4$

$J_a =$ polar moment of inertia about the foundation/soil interface

= 982 ft$^4$

$I_E =$ mass moment of inertia about the elevation axis

= 175 slug-ft$^2$

$I_A =$ mass moment of inertia about the azimuth axis

= 700 slug-ft$^2$

$I_B =$ mass moment of inertia about the foundation/soil interface

= 5610 slug-ft$^2$

$\alpha_A =$ angular acceleration about the azimuth axis

= 2 rad/sec$^2$

$\alpha_E =$ angular acceleration about the elevation axis

= 6 rad/sec$^2$

g = acceleration of gravity

= 32.2 ft/sec$^2$

A = foundation bearing area

= 78.54 ft$^2$

Resonate Frequencies

$f_v =$ resonance frequency in the vertical mode

= $\left(C_u A g / W \right)^{1/2} / 2 \pi$

= 32.9 Hz

$f_r =$ resonance frequency in the rocking mode
Dynamic Response

The reaction torque is the product of the instrument moment of inertia about the rotational axis and its angular acceleration about that axis.

\[ T_E = \text{torque about the elevation axis} \]
\[ = I_E \alpha_E \]
\[ = 1050 \text{ ft-lb} \]

\[ T_A = \text{torque about the aximuth axis} \]
\[ = I_A \alpha_A \]
\[ = 144 \text{ ft-lb} \]

The resistance to rotation about the elevation axis or the static stiffness of the rocking mode and the resistance to rotation about the aximuth axis or the static stiffness of the twisting mode may be calculated as follows.

\[ K_r = \text{Stiffness in the rocking mode} \]
\[ = (2\pi f_r)^2 I_B \]
\[ = 529 \text{ ft-lb/arc-sec} \]

\[ K_t = \text{Stiffness in the twisting mode} \]
\[ = (2\pi f_t)^2 I_A \]
\[ = 1141 \text{ ft-lb/arc-sec} \]

The pitch angle due to the applied torques may be computed as
follows.

\[ \theta_r = \text{pitch angle in the rocking mode} \]
\[ = \frac{T_r}{K_r} \]
\[ = 1.98 \text{ arc-sec} \]

\[ \theta_t = \text{pitch angle in the twisting mode} \]
\[ = \frac{T_t}{K_t} \]
\[ = 1.22 \text{ arc-sec} \]

If the torques were applied suddenly the resultant dynamic pitch angle would double.

\[ \theta_r = 3.96 \text{ arc-sec} \]
\[ \theta_t = 2.44 \text{ arc-sec} \]

Comparing the maximum theoretical dynamic deflections with the maximum allowable deflection found in Step 1; we find that in the elevation axis or rocking mode that the calculated error of 3.96 arc-seconds exceeds the maximum allowable error by less than ten percent, which is insignificant. In the azimuth axis or twisting mode the theoretical value is 2.44 arc-seconds is less than the allowable 3.6 arc-seconds. Therefore the existing foundation meets the criteria for this step.
STEP 4) To determine to what degree external vibrations will affect the foundation it is neccessary to know the characteristics of the vibration and the amplification factor. If the facility and vibration sources are available this information can be obtained from tests or estimated. In the case of the Cine-Sextant the primary sources of external vibrations are the power supply and passing vehicles. Since neither the power supply nor the instrument were available, tests were not made. For the sake of illustration, values for these characteristics were assumed.

Assume that the horizontal acceleration of the power spectral density (PSD) output is $5.0 \times 10^{-10} \text{g}^2/\text{HZ}$ in the vicinity of the 22 HZ rocking mode natural frequency and the amplification factor ($Q$) is 30. Horizontal ground vibrations will cause horizontal inertia forces to act at the center of gravity of the facility.

\[ S_A = \text{acceleration PSD} \]
\[ = 5.0 \times 10^{-10} \text{g}^2/\text{HZ} \]

\[ S_F = \text{force PSD} \]
\[ = W^2S_A \]
\[ = .47 \text{lb}^2/\text{HZ} \]

The inertia force will apply an inertia moment to the facility.

\[ S_t = \text{torque PSD} \]
\[ = Z_0^2S_F \]
\[ = 11.75 (\text{ft-lb})^2/\text{HZ} \]

Assume that this torque PSD is constant over the band width of the rocking mode, the rms value of the pitch angle is as follows.
\[ \theta_{\text{rms}} = \left( \frac{\pi}{2} f_r Q S_T \right)^{1/2} / \left( (2 \pi)^2 I f_r^2 \right) \]

- \( f_r = 22.2 \text{ Hz} \)
- \( Q = 30 \)
- \( S_T = 11.75 \text{ (lb-ft)}^2/\text{Hz} \)
- \( I = 5610 \text{ slug-ft}^2 \)
- \( \theta_{\text{rms}} = 1.01 \times 10^{-6} \text{ rad} \)
- \( = 0.21 \text{ arc-sec} \)

The resulting pitch angle of 0.21 arc-sec is less than the maximum allowable for the assumed horizontal acceleration and amplification factor.

**Conclusion**

Application of the procedure to analyze a foundation for a tracking mount revealed that the foundation for the Cine-Sextant is much thicker than necessary to resist the dead weight and overturning moment, but is just adequate to resist the rocking and twisting forces generated by the tracking mount. It was not possible to make field test to determine the exact response of the foundation to external vibrations.
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