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June 28, 1983 822-1084

Administrative Judges
Gary J. Edles, Chairman
John H. Buck
Christine N. Kohl
Atomic Safety & Licensing
Appeal Board
U.S. Nuclear Regulatory
Commission
Washington, D.C. 20555

In the Matter of
METROPOLITAN EDISON COMPANY
(Three Mile Island Nuclear Station, Unit No. 1)
Docket No. 50-289 (Restart)

Dear Chairman Edles and Judges Buck and Kohl:

Enclosed for the Appeal Board and parties are the following documents:

1. Letter, R. C. Arnold/GPU Nuclear to William Lowe/Pickard, Lowe & Garrick re "Investigation of Potential Safety Issues - TMI-2," dated March 4, 1983, and Attachment.

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830705xxxx Attachment 14

SHAW, PITTMAN, POTTS & TROWBRIDGE
A PARTNERSHIP OF PROFESSIONAL CORPORATIONS

2. Letter, William W. Lowe to R. C. Arnold responding to request for examination of safety issues raised by Mr. King, dated April 25, 1983, and Attachment.

3. Letter, R. C. Arnold to W. W. Lowe/R. W. Griebe re "Report dated April 25, 1983 from Messrs. Lowe and Griebe to Mr. Robert C. Arnold of GPUNC," dated June 8, 1983, and Attachments.

4. Letter, R. C. Arnold to Dr. B. J. Snyder, Program Director, TMI Program Office, NRC re investigation of allegations expressed by Mr. King (attaching items #1-3, above), dated June 9, 1983.

These documents, which previously were provided to the NRC Staff, are being distributed at the Staff's request and because they relate to one of the Staff's identified "open issues" and to TMIA's pending motion to reopen of May 23, 1983.

Respectfully submitted,

Ernest L. Blake, Jr.

Ernest L. Blake, Jr.
Counsel for Licensee

ELB/tjc
Enclosures

cc: Attached Service List

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Appeal Board

In the Matter of	)	
	)	
METROPOLITAN EDISON COMPANY	)	Docket No. 50-289 SP
	)	(Restart)
(Three Mile Island Nuclear Station, Unit No. 1)	)	

SERVICE LIST

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Washington, D.C. 20555

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March 4, 1983

Mr. William Lowe
Pickard, Lowe & Garrick
1200 18th Street, N.W.
Washington, D.C. 20036

Dear Mr. Lowe:

Subject: Investigation of Potential Safety Issues - TMI-2

Confirming our telephone conversation today, I have asked you and Dr. Griebe to perform an independent investigation and evaluation of potential safety concerns raised by members of the TMI-2 staff. I believe that those concerns have been articulated by Mr. Larry King as set forth in the attached memorandum. I requested that you proceed expeditiously with whatever effort is necessary by way of interviews and review of documentation to thoroughly investigate and evaluate these issues.

The attached memorandum also identifies concerns expressed by Mr. King regarding the effectiveness of the management of the TMI-2 program. While your assignment does not encompass those issues, you should have no reluctance to pursue any issues you believe may be relevant to safety of TMI-2 activities.

I understand you will be able to start this activity next week, and I request you give me by March 16, 1983, your sense of how long it will take to complete the investigation and evaluation. It is my expectation that you would provide me with a written report on this investigation and evaluation within the time frame you identify.

You should also be aware that the Company has concerns about outside business activities on the part of Mr. King, which are being pursued separately. Should the Company's pursuit of those issues appear to be having any adverse affect on your investigation, you should notify me immediately.

Mr. John Barton will be your contact person for arranging for working space, administrative support, and coordination of interviews. His role in doing that is limited to necessary facilitation of your effort and you should not discuss with him any of the results of your effort.

While you are free to utilize the information developed in this effort in fulfilling your responsibilities as a member of a General Office Review Board, you are reporting directly to me for this assignment and not to Mr. Finfrock, Chairman of the GORB's.

Very truly yours,

RC Arnold

R. C. Arnold
President

slm

cc: I. R. Finfrock (w/attach)
B. K. Kanga (w/o attach)
P. R. Clark (w/o attach)
H. M. Dieckamp (w/o attach)
L. H. Lilien (w/o attach)

Inter-Office Memorandum

GPU Nuclear

Date March 4, 1983

Subject Concerns of Mr. L. P. King Regarding TMI-2 Activities

To L. P. King

Location

The purpose of this memorandum is to set forth concisely and fully the concerns that you have with regard to TMI-2 activities.

This includes those items identified in the discussion held at your request with Mr. Clark on February 25, 1983. I have reviewed with Mr. Clark his notes from that discussion, and he has reviewed the draft of this memorandum to help ensure that your concerns are understood and properly recorded here.

While we are particularly interested in any concerns you have regarding safety, we are also interested in those concerns you have regarding effective and efficient conduct of all activities at TMI-2.

I recognize that our discussion of these issues is potentially affected by our serious concerns which we have identified to you about your involvement in, or knowledge of, the hiring of GPU System employees by Quiltech, a company of which we understand you are president. However, those issues will be addressed separately.

In the area of safety concerns, it is my understanding that you have the following general concerns:

1. The emphasis on meeting schedules tends to prevent and discourage adequate consideration of potential safety issues.

2. The willingness of some members of TMI-2 management (including Messrs. Kanga, Barton, and Thiesing) to fully consider potential safety issues is inadequate and tends to discourage issues from being raised.

3. Based upon your experience, you concluded that Thiesing cannot be trusted to tell the truth and thus one cannot rely upon his technical work, judgments, and statements relative to safety issues.

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4. There is insufficient involvement by Messrs. Arnold and/or Clark for them to be aware of the fact that safety issues are not being considered adequately in TMI-2 activities.

5. Site Operations Department does not always have sufficient time, and in some instances sufficient technical information, to assure they can adequately fulfill their role relative to safety implications of cleanup activities. For example, the Safety Evaluation Report (SER) may not be available on a timely basis for careful checking by Site Operations of the related procedures against the final SER.

6. The practice of providing "draft" procedures to the NRC is being used to pressure Site Operations to sign off on procedures without adequate consideration of potential safety issues.

7. Bechtel's initial technical work products are sometimes inadequate.

8. Preparation of engineering changes and procedures which control TMI-2 activities is sometimes not in accordance with appropriate requirements; e.g., sometimes systems, equipment, engineering changes, or procedures are inappropriately classified as not "important to safety" and thus related activities are not subjected to the appropriate safety and QA/QC reviews (this problem is partly the result of the need to update the Quality Classification List which helps to control and determine those decisions).

9. Minutes of some meetings do not document potential safety issues that are raised during the meetings.

10. There is insufficient involvement by QA/QC, Site Operations, and the Safety Review Group in work done by Mr. Thiesing's department and thus inadequate assurance of safety; e.g., the polar crane repairs and modifications will not get reviewed by Site Operations and QA until after the crane has been used to make significant lifts above the reactor.

While it is my understanding that you do not know of any activity that has been carried out that was unsafe, there are specific examples (in addition to those cited above) as to how those previously described circumstances have created the potential for work to be done without adequate requirements for safety. You have documented a number of these over the last several months by means of memoranda and copies of these memoranda are contained in Site Operations files. Some of the specific ones that you can recall are:

1. NRC contacted you about improper safety classification of some equipment or procedures and you told them this was a frequent problem. NRC (Barrett) said NRC would follow up and you believe the classification was changed. Ron Warren has documented concerns about the issue in several memoranda.

2. Minutes of Head Lift Status Meetings do not reflect issues raised during the meetings.

3. You and Mr. Gischel (who is very knowledgeable about cranes) were specifically instructed not to get involved in the preparation for restoration and testing of the polar crane because it was not the responsibility of Site Operations.

4. Mr. Barton was critical of your memorandum which documented that you and Mr. Gischel had been told not to get involved in the preparations for the polar crane restoration and testing.

5. The Bechtel-prepared draft SER for the polar crane restoration and testing was considered by the NRC to be of very poor quality, and they requested a thorough review of the SER by GPUN.

6. You concluded the subsequent revised SER for the polar crane was also technically inadequate.

7. Messrs. Kanga and Barton were unwilling to address adequately your concerns about the polar crane. However, you agree that if the load drop accident calculations are valid and a careful review by QA/QC is accomplished properly (and any items identified are resolved) then the polar crane restoration and testing program will be technically adequate. Nevertheless, you advocate a review of whether ALARA and schedule considerations in fact outweigh the benefits of a more extensive testing and inspection sequence for requalification of the polar crane.

8. Site Operations (specifically Mr. Gischel and you) had inadequate opportunity to review the basis for the polar crane restoration and test program before being asked to "sign off" on the polar crane SER.

9. You and QA (Ballard) had to force the issue to get Freemerman to agree that administrative procedures AP 1043 and AP 1047 applied to polar crane testing.

10. You are not sure that all repairs to the polar crane involved replacement "in kind." If that is not the case, the work should have been controlled as a modification to the crane.

11. You are not sure that the load drop analysis described in the polar crane SER was in fact actually done although Bechtel claims it was done.

12. You are not sure that the GORB minutes, Recommendations, and Action Items reflect the issues discussed by them during their review of the polar crane program.

13. The draft SER for the measurement of radiological conditions under the reactor head was not finalized in time to support the schedule so a decision was made to proceed based upon the SER for the "Quick Look." You question whether the procedures prepared based on the draft SER was consistent with the "Quick Look" SER. Only the Safety Review Group (Kunder) reviewed the draft procedures against the "Quick Look" SER--the Site Operations staff did not. The SRG approved the procedures "subject to comment" which is not the normal practice. The draft procedures were furnished to the NRC and they commented negatively on the preparation process for the procedures.

With regard to the effectiveness of the management of the TMI-2 program, you have the following general concerns:

1. Bechtel personnel are inefficient and in many instances incompetent.

2. Activities such as engineering, procurement, and procedure preparation are not being scheduled on an integrated basis along with the field work. This is causing inefficiencies as well as having the implications to safety discussed above.

3. You have tried to have your concerns addressed by Messrs. Barton and Kanga without success. In addition, they are either failing to identify your concerns to me or I am failing to address them and "hiding behind" Mr. Kanga.

Some specific examples you consider to be illustrative of the deficiencies of the management are:

1. Bechtel failed to complete on time the ECM for installation of equipment for measuring water level during the draining of the Steam Generators. Therefore, you had to provide an alternative means and get NRC approval for the associated procedures.

2. GPUN established a schedule of mid-1983 for obtaining gas and liquid samples for the purification system demineralizer and then advanced the schedule to an earlier date because of pressure from the NRC. This caused you to have to pursue the effort on a "crash" basis instead of at a more deliberate pace.

3. You believe Site Operations has accomplished decontamination in the Auxiliary Building at a much lower cost then would have been the result if Bechtel had managed that work as originally planned.

4. You tried to get these concerns addressed by Barton and his management at the time of your annual performance review and were unsuccessful.

On a related subject, you believe that Bechtel (perhaps with directions from GPUN) contacted Quiltech, the company of which you are president, for the purpose of either:

1. Offering work to your firm in return for your being quiet about your concerns; or

2. Trying to compromise you with GPUN (perhaps relative to the GPU Conflict of Interest Policy).

I also understand that you believe you were suspended on February 24, 1983 (while the Company investigated your involvement with Quiltech and its employment of GPUN personnel) in retaliation for your having stated your concerns about TMI-2 activities.

To the best of my knowledge this memorandum describes all of your significant general concerns as to safety and effectiveness of TMI-2 activities. Please let me know if there are any other concerns which you believe need to be addressed and resolved.

RCArnold

R. C. Arnold

slm

cc: P. R. Clark
H. M. Dieckamp
B. K. Kanga

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April 25, 1983

Mr. Robert C. Arnold
President
GPU Nuclear Corporation
Post Office Box 480
Route 441 South
Middletown, Pennsylvania 17057

Dear Mr. Arnold:

The letter to you of instant date enclosed hereunder responding to your request for an examination of safety issues raised by Lawrence F. King has been signed by me. It has been read in its entirety to Dr. Roger W. Griebe and sent to him for his signature, which we expect to receive within a few days, at which time we will forward it to you.

Very truly yours,

William W. Lowe

WWL:ils

Enclosure

Mr. William W. Lowe
Pickard, Lowe & Garrick, Inc.
1200 18th Street, N.W., Suite 612
Washington, D. C. 20036

Dr. Roger W. Griebe
2151 Craig Avenue
Idaho Falls, Idaho 83401

April 25, 1983

Mr. Robert C. Arnold
President
GPU Nuclear Corporation
Post Office Box 480
Route 441 South
Middletown, Pennsylvania 17057

Dear Mr. Arnold:

This responds to the request[1,2] that we examine safety issues raised by TMI-2 staff, particularly, as articulated by Lawrence F. King[3,4,5].

To start with, as far as we can determine, there are no allegations that actual physical operations have been unsafe. Nor have we found evidence that they have been. Rather, the issues are whether technical analyses, procedures and practices are adequate to keep them safe, particularly in respect to use of the polar crane.

The issues we deal with are: I. Safe Use of the Polar Crane, II. Safety Classification of Equipment, III. Procedures, IV. Minutes of Meetings, V. Schedule Pressures, VI. Clarity of Responsibility, VII. Management Matters Affecting Safety, and VIII. NRC Actions. We find as follows:

I. SAFE USE OF THE POLAR CRANE

The safe use of the polar crane to remove the shield blocks and to lift the reactor vessel head is still under review by the GPUNC safety review process and the NRC. We do not prejudge the outcome. The use of the polar crane can be made safe by subjecting proposed activities to such review provided matters listed in Appendix A hereto are considered.

Preventing a load drop should be the overriding safety objective. Protecting the public health and safety from direct effects of a drop is encompassed by it and is easier to demonstrate. And achieving it reduces chances of delaying recovery operations to the detriment of public health and safety.

Mr. King(3,4) and others(5,6,7) were critical of the technical quality of the polar crane Safety Evaluation Report(9). Our review indicates Revision 0 of this document is not, by itself, complete enoug' to serve the safety review and approval process well and, apparently, supporting documents and information were not made available for such review in a timely manner. Appendix A lists some documents, calculations and other information which should be considered in the safety review process.

II. SAFETY CLASSIFICATION OF EQUIPMENT

The level of safety review, surveillance, maintenance, quality assurance and quality control applied to any activity or equipment is determined by whether the equipment involved is classified as IMPORTANT TO SAFETY (ITS) or NOT IMPORTANT TO SAFETY (NITS). The system for making these determinations has been questioned(3). In our view and that of others(10,11), it should be improved.

It is more difficult to do work involving ITS than NITS equipment. This fosters a tendency by those responsible for doing work to justify NITS classifications. On the other hand, those responsible for safety review or approval tend the other way. The issue is whether such tendencies are properly balanced in the interests of safety. When the ITS list and related tools are not specific enough for the intended use and/or do not reflect current plant status, as has been the case, the area for dispute is widened and it is more difficult to strike a proper balance without seeking settlement of disputes at too high a level in the organization.

The complaint about misclassification can be resolved and the system made adequate by completing the current effort to make the ITS list more specific and current to the extent needed for control of plant status. In addition, the safety classification of all equipment in each recovery operation (i.e., for each Unit Work Instruction) should be specified de novo in work plans subject to safety review. Such determinations should be made using a simplified and clarified definition of ITS which recognizes the importance of cleaning up TMI-2 expeditiously as part of the objective of protecting the health and safety of the public.

III. PROCEDURES

The level of management and safety review applied to any activity at TMI-2 is established by the GPUNC Administrative Procedures(12,13,14,15). The procedures have not always been followed(16), in part, for reasons cited below.

It is more difficult to do work if GPUNC procedures are applied to recovery operations than if procedures typical of those used for engineering and constructing a new plant are applied. The TMI-2 team members whose careers have been in engineering and construction have exhibited impatience with GPUNC procedures which derive from the complex and interwoven procedural environment of an operating plant. These team members lead recovery activities and tend to seek ways to do work which do not involve the more cumbersome procedures. On the other hand, those responsible for complying with provisions of the TMI-2 License, and whose background is in plant operations, tend to disagree with this approach. The fact is, however, that compliance with GPUNC procedures is required at the site and, in some cases, has not been honored[16,17].

The GPUNC procedures and the related management and safety reviews are adequate for safe conduct of work at TMI-2 in the literal sense. However, to the extent that they, or the requirements that they impose, are unnecessarily complex, burdensome and lengthy[18,19,20,21], they detract from safety because they delay cleaning up the plant. Although work is underway to resolve this issue, it has not ~~yet been resolved~~[22]. The procedures and compliance with them should be improved.

IV. MINUTES OF MEETINGS

We did not find concealment of significant safety issues by excluding them from minutes of meetings[3,4]. Our investigation was not exhaustive enough to confirm that it never happened. We note, however, that there can be disputes about what is significant or pertinent enough to be included. We also note that should a participant in a meeting believe such concealment has occurred, he is, in our view, obligated to report it in writing.

More specifically, Mr. King is said not to have been sure that General Office Review Board (GORB) Minutes reflect polar crane issues discussed by GORB[3]. The GORB did issue a formal written recommendation to the President of GPUNC on this matter immediately after considering it at its meeting of February 10[11]. If past practice is followed, the recommendation will be incorporated in GORB meeting minutes.

V. SCHEDULE PRESSURES

We did not find instances where schedule pressures resulted in demonstrably unsafe operations in the matters we have investigated. However, the time-consuming cycle of reviews and approvals for documents like Engineering Change Memorandums and Safety Evaluation Reports and Operating Procedures have been aggravated by late receipt of prerequisite and supporting documents and information. This may well result in inadequate time for review, especially for those who have to act at the end of the chain of review and approval. It has resulted in pressure,

especially at the end of this chain, to resolve issues in a time period which is too short for adequate review.

We concur with the view that improved integrated schedules are needed. Such schedules should include due dates for all reviews, concurrences and approvals required for any work unit at the time the work unit is planned. The schedule for these actions and the information to support them should be kept current and should be policed for compliance.

VI. CLARITY OF RESPONSIBILITIES

Mr. King says[4] he was informed that his signing off on the polar crane did not signify his approval of the safety evaluation reports[9] on that subject. This is consistent with previous correspondence[8]. It does not appear to be consistent with applicable procedures[13] which say that the signature of a department head in an approval space on a document indicates the "Approver" bears the ultimate responsibility for all aspects of the document.

Mr. Kanga, noting that Mr. King and Mr. Gischel had a different perception of safety requirements for the polar crane load test[23], said he would, nonetheless, proceed utilizing the safety evaluation in question. This exercise of management prerogative apparently waived either the requirement for, or the definition of, "approval". This is a typical management prerogative exercised to resolve disputes. In the case of TMI-2, however, it would seem prudent to clarify ahead of time the procedures governing the settlement of disputes as is further discussed in Section VII.

VII. MANAGEMENT MATTERS AFFECTING SAFETY

All of the items discussed above are management matters affecting safety. But there are several others. The willingness of senior management to fully consider safety issues is questioned[3]. A question has also been raised as to whether Messrs. Arnold and Clark have been sufficiently involved to be aware that "safety issues are not being considered adequately"[3].

We found no instance of unwillingness in the Office of the President of GPUNC (Messrs. Arnold and Clark) or in the Office of the Director of TMI-2 (Mr. Kanga). Nor was there such evidence, per se, at the department level, although there were some strong disagreements at that level about the resolution of safety issues[19]. When a serious dispute did arise about the polar crane[3,4,5,6,7,8] and resolution at a lower level failed, senior management became involved[3,23,24,25,26].

We have found that senior management has been made aware of significant safety issues in dispute at the department head level. We would not expect them to be aware of issues resolved or still being

considered in the safety review process except to the extent needed to assure themselves that the process is working properly. However, senior management should be informed promptly whenever an unresolvable dispute develops at the Division/Department head level or higher.

VIII. NRC INVOLVEMENT

Review of documentation shows conclusively that the NRC has acted properly and independently as regards safety issues. The NRC has issued citations, questioned procedures and safety evaluations and conducted extensive inspections. On occasion claims of "Informal" NRC approval have been used by some TMI-2 personnel to argue for approval by those responsible for concurrence and approval in the GPUNC safety review process. This practive should be stopped. But professional communication on technical issues should be encouraged between the NRC and the TMI-2 staff.

Very truly yours,

William W. Lowe

William W. Lowe

Roger W. Griebe

WWL/RWG:ils
Enclosures

APPENDIX A
POLAR CRANE SAFETY CONSIDERATIONS

(1) Written documentation should be provided to demonstrate that if the first 40-ton missile shield block is dropped free from its test holding position, approximately six inches above its foundation, neither it nor its foundation will fail and fall.

(2) Before lifting the second 40-ton shield, the first one should be used to conduct a braking test by rapid release of the control button at the pendant control station. The load for the test should be positioned to minimize damage should the brakes fail.

(3) A report should be submitted for safety review which shows the calculated vs. allowable loads on the lifting rig for the 40-ton shield blocks assuming all of the load will be taken by any two diagonally opposite lifting lugs and associated rigging.

(4) Non-destructive examination of each "new" structural element of test rigs should be conducted before they are used to demonstrate by other than visual means that they are not cracked or defective, and to verify their dimensions. By non-destructive methods we mean magnetic particle, dye penetrant, ultrasonic tests, or load tests at or above the calculated maximum loads to be incurred during planned lifts. The "old" equipment (that which has already been used to lift the head) should be thoroughly examined visually for cracks and measured for dimensional conformance with design specifications.

(5) A test load of 210 tons or more[27] along with other measures to be taken are adequate to qualify the crane for the head lift even though lower than recommended by applicable standards[28] provided that the head lift load is as described, that friction and interference forces do not add substantially (i.e., greater than 10%) to the load during head lift and provided other steps outlined herein and other matters currently questioned are considered.

(6) The 210-ton (nominal) test load sequence should include a braking test analagous to that in item 2 above.

(7) The planned pathway for moving the shield blocks from the load test area to the storage position on the "D" ring involves moving them close to the reactor pressure vessel. Consideration should be given to load pathways which move them along a paths further from the reactor vessel.

(8) A written report should be provided for safety review which supports with quantitative estimates the judgment that ALARA considerations mitigate against conducting a load test to recommended standards[28] to qualify the crane for the first missile shield lift. The report should compare man rem exposure estimates with and without the inclusion of this test in the total Polar Crane load test sequence.

(9) A review of electrical circuitry should be made and documented to show whether or not there are failure modes (e.g., by a single phase fault path other than that already identified) which could keep the mechanical brake magnets energized at the same time the drive motor torque is diminished. If there are, the probability of their occurrence should be estimated.

REFERENCES

(1) Letter, Arnold to Lowe, "Investigation of Potential Safety Issues - TMI-2," March 4, 1983

(2) Letter, Arnold to Griebe, "Investigation of Potential Safety Issues - TMI-2," March 4, 1983

(3) Memo and Letter, Arnold to King, "Concerns of Mr. L. P. King Regarding TMI-2 Activities," March 4, 1983

(4) Letter, King to Arnold, March 23, 1983, responding to Arnold's Memo of March 4, 1983

(5) Memo, E. H. Gischel to L. P. King, 4240-83-111, "Review of Polar Crane Load Test Safety Evaluation," February 10, 1983

(6) Memo, R. L. Freemerman to E. H. Gischel, 4300-83/F-0002, "Polar Crane Load Test Safety Evaluation," February 17, 1983

(7) Memo, E. H. Gischel and L. P. King to J. W. Thiesing, 4240-83-138, "Polar Crane Load Test Safety Evaluation," February 17, 1983

(8) Memo, L. P. King to J. J. Barton, 4200-83-034, "Polar Crane," January 20, 1983

(9) Safety Evaluation Report for the Polar Crane Load Test, TMI-2, Rev. 0, February, 1983

(10) Memo, D. R. Buchanan to Baker, Ballard, Byrne, Gischel, Hansen, Hildebrand, Kelly, King, Kunder, Larson, Marsden, Prabhakar and Rider, 4340-83-0146, "Update of ITS Definition and QCL," February 25, 1983

(11) Memo, Ivan R. Finfrock, Jr. to R. C. Arnold, TGR-1-126 & TGR-2-46, "GORB Meeting Reports - TMI-1 No. 52 and TMI-2 No. 15," February 15, 1983

(12) 4000-ADM-3000.01, Rev. 0, TMI-2 Unit Administrative Procedure Manual," TMI-2 Unit Work Instructions," 01/03/83

(13) 4000-ADM-1000.01, Rev. 0, TMI-2 Unit Administrative Procedure Manual, "TMI Unit 2 Organization, Responsibility, and Authority," 01/03/83

(14) TMI Unit No. 2 Administrative Procedure 1043, Work Authorization Procedure, Rev. 2, 08/30/82

(15) TMI Unit No. 2 Administrative Procedure 1047, Startup and Test Manual, Rev. 0, 01/26/81

(16) Quality Deficiency Report (QDR), CHK-011-83, J. F. Marsden, 3/8/83

(17) TMI Nuclear Station, Assessment of the Implementation and Effectiveness of the Quality Assurance Program, February, 1983

(18) Memo, Kanga to Ballard, King, Larson & Thiesing, 4000-82/K-442, "ECM Reviews and Approvals," November 11, 1982

(19) Memo, Fornicola to Ballard, OQA-347- TMINS, "Unauthorized Work Activities Related to Unit 2 Recovery Programs," February 3, 1982

(20) TMI Nuclear Station, Assessment of the Implementation and Effectiveness of the Quality Assurance Program, May, 1982

(21) TMI Nuclear Station, Assessment of the Implementation and Effectiveness of the Quality Assurance Program, October, 1982

(22) TMI Nuclear Station, Assessment of the Implementation and Effectiveness of the Quality Assurance Program, November, 1982

(23) Memo, Kanga to Arnold, 4000-83-110, "Safety Evaluation Report for Polar Crane Load Test," February 18, 1983

(24) Ballard to Kanga, 6110-83-039, "Polar Crane Safety Evaluation," February 23, 1983

(25) Kanga to Arnold, 4000-83-153, "Polar Crane Readiness Review Committee Meeting," March 22, 1983

(26) Leighton to Kanga, "Management Readiness Review for Polar Crane March 12, 1983," March 14, 1983

(27) Crane Test Procedure, 4370-3891-83-PCI," April 7, 1983

(28) ANSI B30.2.0 - 1976, Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder)

GPU Nuclear

GPU Nuclear Corporation
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717 944-7621
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June 8, 1983

Mr. William W. Lowe
Pickard, Lowe & Garrick, Inc.
1200 18th Street, N.W.
Suite 612
Washington, D.C. 20036

Dr. Roger W. Griebe
Aisling, Inc.
2151 Craig Avenue
Idaho Falls, Idaho 83401

Dear Messrs. Lowe and Griebe:

Re: Report dated April 25, 1983, from Messrs. Lowe and Griebe to Mr. Robert C. Arnold of GPUNC

This letter is in response to the subject report. The response will deal with each of the eight (8) issues in the report:

I. SAFE USE OF THE POLAR CRANE

The response to the items listed in Appendix A, "Polar Crane Safety Consideration" is being sent to you separately. Also, calculations requested by you and referred to in responses to Appendix A will be forwarded to you with the responses to Appendix A.

II. SAFETY CLASSIFICATION OF EQUIPMENT

The role of the plant systems and equipment originally classified as "IMPORTANT TO SAFETY" (ITS) has changed significantly since the accident. Various systems which were required for safety of operations prior to the accident are no longer required for maintaining the plant in a safe condition. Appropriate engineers must look at systems and components in light of today's requirements to determine whether that system or component is ITS or not. We are putting higher priority on completing the current effort to reclassify, where appropriate, systems and equipment. We will also take steps to maintain the classifications current. In the course of this effort we are trying to simplify the definition of ITS activities and equipment. We believe this will result in the recommended improvement in the process for making determinations of whether an activity is ITS or NITS.

We also believe that conditions at TMI-2 and the nature of the work effort are such that "cookbook" type definitions are not sufficient. Consequently, we envision a major effort in educating the organization by examples to ensure that judgments made regarding ITS or NITS classifications are appropriate. It is our intent, and we will continue its implementation, to include in work procedures as specifically as practical, the activities contained within the work procedures which are important to safety. This, in combination with an updated listing of equipment which is ITS, should provide a sufficient basis for assuring proper control of the work.

It is our understanding that your investigation did not identify any instances of significance where equipment or activities were improperly classified or where equipment or activities were deliberately misclassified to circumvent otherwise required administrative controls.

III. PROCEDURES

In your review of the use of GPUNC administrative procedures, the following statements are made in the report:

> "The procedures have not always been followed (16), in part, for reasons cited below."

> "The fact is, however, that compliance with GPUNC procedures is required at the site and, in some cases, has not been honored (16, 17)."

It is our understanding that those two quotations refer to judgments made by you based upon your investigation and evaluation of the facts concerning procedural compliance. It is also our understanding that you did not identify instances of deliberate violation of procedural requirements but that the instances identified by your investigation were the result of lack of understanding by members of the organization as the applicability of procedures to activities being conducted or unfamiliarity with applicable procedures. That assessment of the situation is consistent with the assessment provided to me by Blaine Ballard, Manager-Quality Assurance, TMI.

The Quality Assurance Department has provided Mr. Kanga with information and analysis of Quality Deficiency Reports issued at TMI-2 during 1982. I am attaching memorandum #6610-83-069 dated May 3, 1983, "QDRs Applicable to TMI Unit 2." You will note that the number of QDRs issued in 1981 was 96; the number of QDRs issued in 1982 was 45; and the number of QDRs issued in the first quarter of 1983 was 7. This indicates an improvement in the quality of work performed at TMI-2, including compliance with procedures.

We will continue our efforts to fully implement the new procedures system instituted on January 1, 1983, with high priority being given to the training of all supervisors and professional staff members on the requirements and objectives of the procedures. We also will continue to have strong Quality Assurance Department review of the organization's compliance with procedures.

IV. MINUTES

No comments.

V. SCHEDULE PRESSURES

I am happy to note in the report that:

> "We did not find instances where schedule pressures resulted in demonstrably unsafe operations in the matters we have investigated."

In spite of any schedule pressures that may exist at the end of the chain of events, I am not aware of any instances where management insisted on resolution of differing opinions without proper discussion. The organization does have to insist on a conclusion to such discussions in an appropriate time frame while still providing for all points of view to be expressed and considered. The Company recognizes that the elements of the organization that are responsible for completing the last steps of an effort which must proceed in sequence through the organization will be under the heaviest pressure to compensate for slippage experienced during earlier steps of the work effort. We not only accept that sufficient time must be provided, but we insist that adequate time be taken to perform safety-related work efforts properly. We recognize that on this project, schedules need to be modified when new information is available on the condition of the reactor or various systems, and this circumstance will result in additional pressures on everyone to minimize schedule slippage.

We believe that within the general industry use of the nomenclature, we are utilizing appropriate schedules for overall management of the work. It is appropriate for schedules to be set by management and progress of the work statused against the official schedule as opposed to just changing schedules day-to-day depending upon work progress. However, we will look at whether job or task planning has sufficient detail provided so that the various organizations:

1. understand the time allocated for activities for which they are responsible;

2. the inter-relationships of the various activities, including their mutual constraints; and

3. the visibility those documents give the organization on the status of the job components.

VI. CLARITY OF RESPONSIBILITIES

We agree that Reference 13 - 4000-ADM-1000.01, Rev. 0, TMI-2 Unit Administrative Procedure Manual, "TMI-2 Unit Work Instructions," 01/03/83, states that the signature of a department head in an approval space on a document indicates the "Approver" bears the ultimate responsibility for all aspects of the document. However, Mr. King did not sign the polar crane safety evaluation report as an "Approver." His role was one of reviewing the SER content from the perspective of Site Operations. Mr. Kanga was responsible for the content of the SER inasmuch as he was the individual who submitted it to the NRC. We will be revising Reference 13 to make clear the procedures for exercise of management prerogative when necessary to resolve disputes.

VII. MANAGEMENT MATTERS AFFECTING SAFETY

The procedures referred to in the preceding paragraph will include requirements for informing senior management "promptly whenever an unresolvable dispute develops at the division/department head level or higher." My experience is that even without formal guidance, such has been the practice throughout GPUNC. Specifically, with regard to significant polar crane issues, I was informed by Mr. Kanga on a timely basis.

VIII. NRC INVOLVEMENT

The report states:

> "On occasion claims of 'informal' NRC approval have been used by some TMI-2 personnel to argue for approval by those responsible for concurrence and approval in the GPUNC safety review process. This practice must be stopped."

This project requires that the NRC staff have good visibility as to planning and plans for conducting essential clean up work. It is unrealistic to expect that opinions and judgments expressed by individual NRC staff members will not be reflected during subsequent internal discussions. However, written instructions have been provided to the staff that claims of informal NRC approval should not be used as justification for one or the other side of a discussion point.

Mr. William W. Lowe
Dr. Roger W. Griebe
Page 5
June 8, 1983

I have asked Mr. Kanga to provide additional supporting information for the response to Item 8 of Appendix A of your report. I will forward it when it becomes available.

I appreciate your efforts in reviewing the issues addressed in your report. Those efforts have been very helpful to the TMI-2 program. Your report and this response will be provided to Mr. Ed Stier, who is conducting a full investigation of all allegations made by Messrs. King, Gischel and Parks and Ms. Wenger. Your report and this response will also be provided to the NRC.

Sincerely,

RC Arnold

R. C. Arnold
President

slm

Enc.

cc: B. K. Kanga
E. H. Stier, Esq.

Inter-Office Memorandum

Date May 3, 1983

GPU Nuclear

Subject QDR's Applicable to TMI Unit 2

6110-83-069

Location TMI Trailer 175

To B. K. Kanga
Director - TMI-2

The attached information is an analysis of all QDR's issued relative to TMI Unit 2 in 1982. The following information is presented:

1. Attachment 1 is a breakdown of all QDR's including those which were issued as a result of formal monitorings performed by Operations QA, as well as field initiated QDR's.

2. Attachment 2 is a further breakdown by percentage and number of QDR's which were field initiated (i.e., other than as a result of monitoring).

3. Attachment 3 is a table of normalized numbers. These normalized numbers are derived by comparing the percentage of QDR's issued to each organization as a result of monitorings to the percentage of monitorings performed on that organization. Normalized values were not derived for field initiated QDR's since there is no good measure of the percent of inspection time spent with each organization.

The total number of QDR's issued in 1982 (45) is considerably less than the number of QDR's issued in 1981 (96). Similarly, for the first quarter of 1983, a total of seven (7) have been issued which would indicate a further positive quality trend in overall performance.

To evaluate the significance of potential trends identified in certain Unit 2 organizations and activities, further evaluations were performed. The following conclusions were reached:

1. Plant Engineering in Unit 2 has a high normalized number of QDR's. However, the eight QDR's are distributed among seven activities with no apparent connection of QDR's. No specific trend is indicated.

2. Unit 2 activities of Modification/Installation have a high normalized number. Modifications/Installations has a total of three QDR's. The actual number is too small to determine if there is an unsatisfactory trend.

3. The Unit 2 activity of Fire Protection has a high normalized number of QDR's. A total of six QDR's were issued for this activity. An investigation into these QDR's was completed to determine if an unsatisfactory trend existed.

   It was determined that the QDR's were issued to five different departments. Some of the reasons were: "lack of weekly fire inspections", "lack of calibration", "welding fire violations", etc. All the reasons are unique

A0000648

and appear to be unrelated. There is no indication of a trend for this activity.

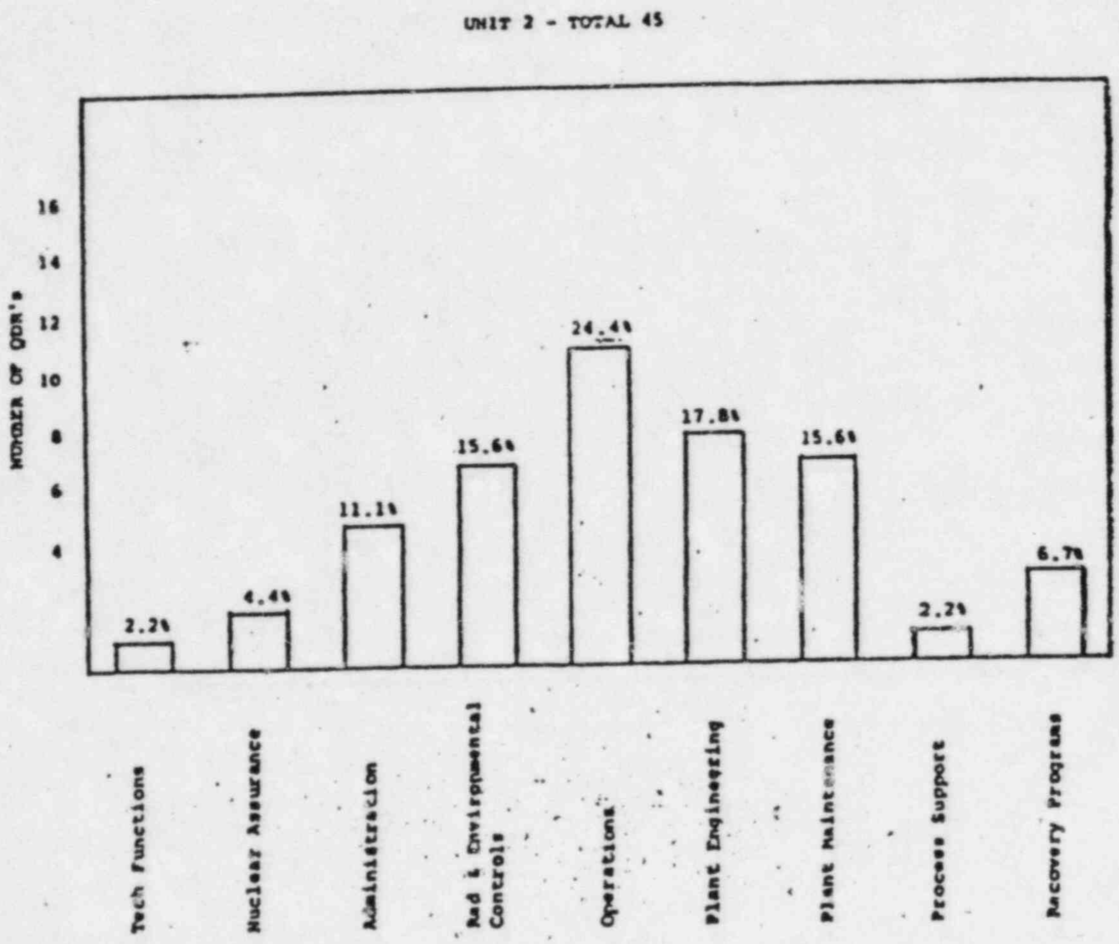
The above analysis is provided for your information and use as appropriate.

B. E. Ballard, Sr.
Manager - TMI QA
Modifications/Operations

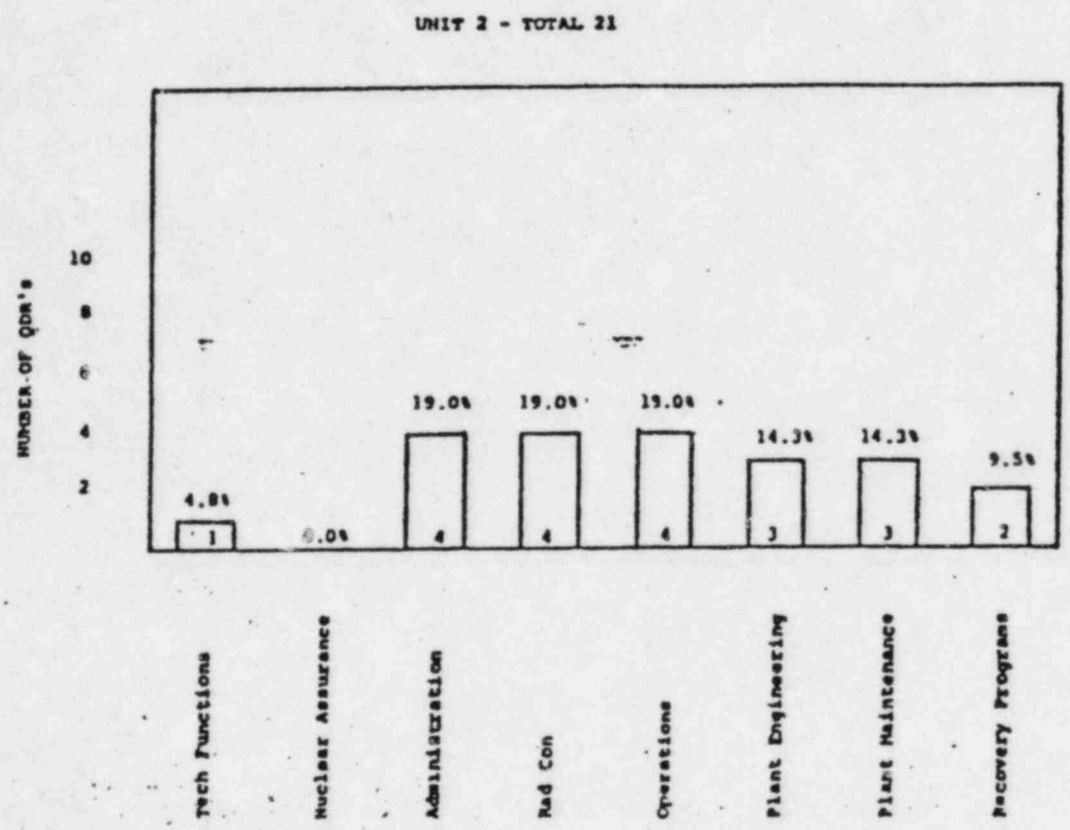
BEB:JJP:cam

cc: File
CARIRS

1982 QDR's BY ORGANIZATION



FIELD INITIATED QDR's BY ORGANIZATION



1982 NORMALIZED NUMBER OF QDR's BY ORGANIZATION

Normalized Number = $\frac{\text{Percent of QDR per Activity}}{\text{Percent of QAHD per Activity}}$

UNIT 2

TOTAL QDR's - 24

	Nuclear Assurance	Administration	Rad Con	Site Operations	Plant Engineering	Plant Maintenance	Process Support	Recovery Programs	Tech Functions
- Normalized Number	1.0	.6	.8	1.0	2.2	.8	[illegible]	1.6	0.0
- Percent of Total QAHR's	8.3%	7.4%	16.4%	29.4%	9.6%	21.0%	4.7%	2.6%	.5%
- Percent of Total QDR's	8.3%	4.2%	12.5%	29.2%	20.8%	16.7%	4.2%	4.2%	0%
- Actual Number of QDR's Resulting from Monitoring	12	1	3	7	5	4	1	1	0

Appendix A
Polar Crane Considerations
Responses

1. A formal calculation (C-1-10, attached) has been prepared, which includes an analysis of a six inch drop of the first 40 ton missile shield to be lifted. For the initial lift at this height the shield is not free of its vertical support studs. Therefore these studs serve as guides, precluding the possibility of a drop other than at the original stored position. Because of this constraint, the worst impact is for both edges of the shield to impart simultaneously on the supporting "foundation" walls. The critical area is the flexure at the center of the missile span. Results of the calculations show that although the reinforcing steel stresses in this area may exceed yield, as expected, they remain well within the allowable strain limits with substantial reserve energy absorption margins. Additionally, calculation C-1-5, attached, demonstrates that the drop of one missile shield onto another will not cause failure of the missile shield.

2. The Polar Crane Load Test Procedure (UWI-4370-3891-83-PC001, Rev. 3) requires that after raising the first missile shield six inches and holding for five minutes, the missile shield then is to be lowered three inches and held again. The missile shield is raised and lowered using the slow speed and stopped by the operator releasing the pushbutton. This step in the procedure satisfies this recommendation. (See procedural steps 9.3.1.2 and 9.3.1.3).

3. The four (4) wire rope slings designed to lift the missile shields were furnished equal length within a tolerance of ± 1/8" per supplier certification. In addition, the rigging for the missile shields has been designed with load equalizing capabilities built-in. Bechtel Drawing 2-COP-1302, Rev. 2, shows the details of the Missile Shield Rigging Attachment Plate (Detail 5) using a pair of two-leg bridles rather than a single four-leg bridle. Therefore, the rocking action of the attachment plate (see Enclosure 1 attached) about its single pin and the two Crosby shackles, with two sling eyes each in the bail (see Enclosure 2 attached), provide equalizing action to accommodate the tolerance in the sling lengths.

   To demonstrate the load equalizing capabilities built into the missile shield rigging design, a calculation has been performed to assess the effect of tolerances in the sling lengths and lifting lug placement (effective sling length). The calculation determines the maximum difference in the effective sling lengths which could be tolerated and still maintain a safety factor of 5 in each individual sling. The calculation accounts for the load equalizing effect of rope strain, hook rotation on its swivel, the rocking action of the pinned plate link, and lateral movement of the slings in their respective shackles. The worst case occurs in this 4 sling arrangement when the shorter slings are attached to diagonally opposite corners. The calculations show that, by considering the equalizing capability of the system, the flexibility of the rope, and the breaking strength of the ropes actually furnished, a difference in effective sling length of 7/16" can be tolerated while maintaining a safety factor of 5 in the shorter slings.

It is recognized that tolerances in the construction of the missile shields and fabrication of the rigging hardware could result in additional differences in the effective length of the slings. The safety factor of 5 used in the sling design was selected, in part, to account for such variations.

Even in the extremely unlikely situation where the combined effect of all tolerances causes the safety factor of the 4 sling system to fall below 5, the safety of the lift should not be a concern. For this worst case situation, the maximum load that would be lifted by a single sling is about 40% of its minimum breaking strength. Each sling was proof tested to a load of 40% of the minimum breaking strength. The slings therefore have been shown by actual load test to be capable of handling the maximum out-of-tolerance loading condition. As can be seen from Enclosure 3 attached, this load is well below even the yield point of the rope.

Enclosure 4 summarizes available reference material on multiple sling lifts. As can be seen from Enclosure 4, the body of opinion is not unanimous regarding the proper method for specifying safe working loads for four sling lifts. Some of the references of enclosure 4 obviously consider the load equalizing effect of rope strain and rigging realignment; others specifically prohibit such considerations. Since the cost of new slings is not substantial and to avoid a protracted discussion on this point, we have chosen the more conservative approach, that is, to procure a new set of slings for the missile shields which are designed to retain a safety factor of 5 between applied load and minimum breaking strength under the assumption of two-point (opposite corners) lift of the missile shields. The lifting shackles are also designed to retain a safety factor of 5 under the two-point lift condition. The load test procedure, SER, and affected drawings are being updated to reflect this change.

4. The new load test assembly was designed and constructed to the AISC, "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings." This Code, in turn, requires that for the purposes of welding and inspection, AWS D1.1, "Structural Welding Code," be used. AWS D1.1 requires that all welds in structural elements be visually inspected for dimensional verification and overall weld surface quality. The Code provides acceptance criteria for these activities which are considered commensurate with the design conditions.

   The design of the load test assembly was strictly within the conservative limits of the AISC Code, and for which the AWS D1.1 visual acceptance criteria are a standard industry practice.

   NDE, other than visual, is normally considered for structural members when cyclic operation of the members is anticipated. This condition does not exist with the load test assembly, which will undergo only a few dead weight lifts.

   The load test assembly is not considered to be any different than other structural framing arrangements in a nuclear power plant which are subjected to constant loading conditions, i.e., not affected by fatigue considerations. Current standard practice for such members is to require only visual inspection of the welds on these members, which is consistent with the requirements for the new load test assembly.

The load the assembly will handle has been accurately established by calculation and will be closely monitored, by actual load cell readings, to assure that the design load is not exceeded. A major portion of the safety factor provided in the design of a steel structure, including the welds, is due to the uncertainty of the load, the strength of the structure and consideration of cyclic loading during its service life. The absence of these considerations provide additional confidence in the safety margins in the design and construction of the load test assembly.

Finally, the sequencing of the polar crane load test will provide added assurance that the load test assembly and its welds can safely handle the test load. The initial phase of the polar crane load test involves raising the assembly 6" above the floor and holding this position for a specified period of time. Dropping the assembly from this height will not collapse the existing floor slab. Among the items that will be visually checked for during this initial 6" lift will be the yielding or excessive deformation of the structural components of the assembly. This step will provide adequate assurance that the load test assembly can safety handle the load for the remainder of the test.

We find no precedent for NDE of the unwelded links in the rigging which are fabricated of plate steel. This is a tough ferritic steel which is not particularly susceptible to crack propagation.

As a result of undersized welds which were discovered on the Crystal River tripod, (of essentially identical design to the TMI-2 tripod) a dimensional check of the corresponding welds will be performed. The welds in question (see Figure 4) are shown on the attached sketch.

5. The rating of the crane as a result of the load test will be established as either 170 tons or 80% of the test load, whichever is greater. This rating will not be exceeded during head lift as measured by an in-line load cell. If additional capability is required to overcome interference forces, it will be provided by means other than the polar crane, such as jacking.

6. Procedural Step 9.5.2 requires lifting the test load to a height of six inches above the floor. This is the initial lift of the test load and is done in slow speed and stopped by the operator releasing the pushbutton. This step in the procedure satisfies this recommendation.

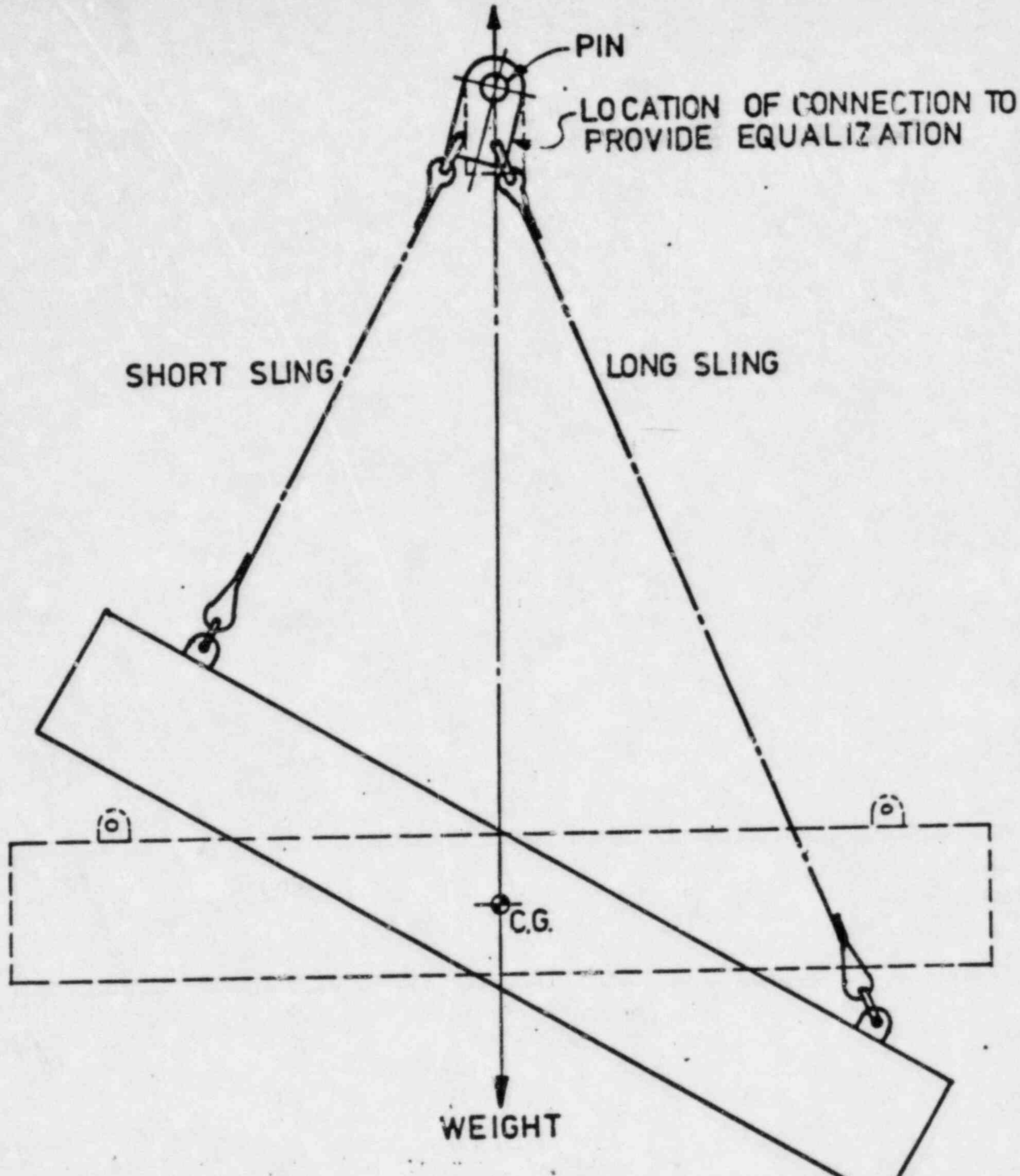
7. The specified missile shield path does not pass over the reactor vessel. The load path could, however, be altered to increase the distance between the load path and the reactor vessel.

8. The applicable ANSI standard (ANSI B30.2-1976) recommends but does not require a load test prior to use of the crane. According to the standard, this advisory recommendation (denoted by "should") is "to be considered, the advisability of which depends on the facts in each situation." We have determined that the preliminary 50 ton load test is not advisable since a failure on initial missile shield lift has been shown to pose no substantive hazard and therefore would imply an unjustifiable expenditure of worker radiation exposure (see below).

The answer to Item 1 above demonstrates that crane or rigging failure on the initial missile shield lift will not fail the missile shield. Additionally, the traverse of the first missile shield over the remaining missile shields has been shown safe by analyses which demonstrate that a crane or rigging failure at this point will not fail the remaining shields. Once the first missile shield is placed on the load test fixture, one can view this as a 100% load test for the missile shields. Since the load is only 8% of the design load for the crane, and subsequent missile shield relocations are similarly fail-safe, the preliminary load is deemed of no engineering value. We estimate an expenditure of over 50 man-rem to bring in 50 tons of dead weight and perform a preliminary load test. Since this is deemed unnecessary from an engineering standpoint, it is not ALARA to perform the preliminary load test, regardless of the specific man-rem expenditure involved.

9. The potential for single phasing of the polar crane main hoist circuitry exists due to failure of various components in the circuitry. The most likely cause would be due to a single phase to ground fault which opens only one phase of the three phase power source previously identified and which will be eliminated by insertion of dummy slugs in the main polar crane disconnect switch on the crane.

Other potential, but low probability, events are possible such as open circuiting of one phase in the secondary slip resistor or motor brush/slip ring assembly; failure of one overload heater (open circuiting); or inadvertent opening of one contact in the three phase contactors. These failures are not practical to circumvent and are not required since the operator can recognize these failures by cessation of lifting in the hoist mode or by increased acceleration in the lowering mode. Required operator action would necessitate release of the main hoist pushbutton thereby setting the brakes. If the brakes did not set (second failure) a main power "off" button on the pendant can be pushed to deenergize the entire polar crane at the cab, thus setting the brakes.

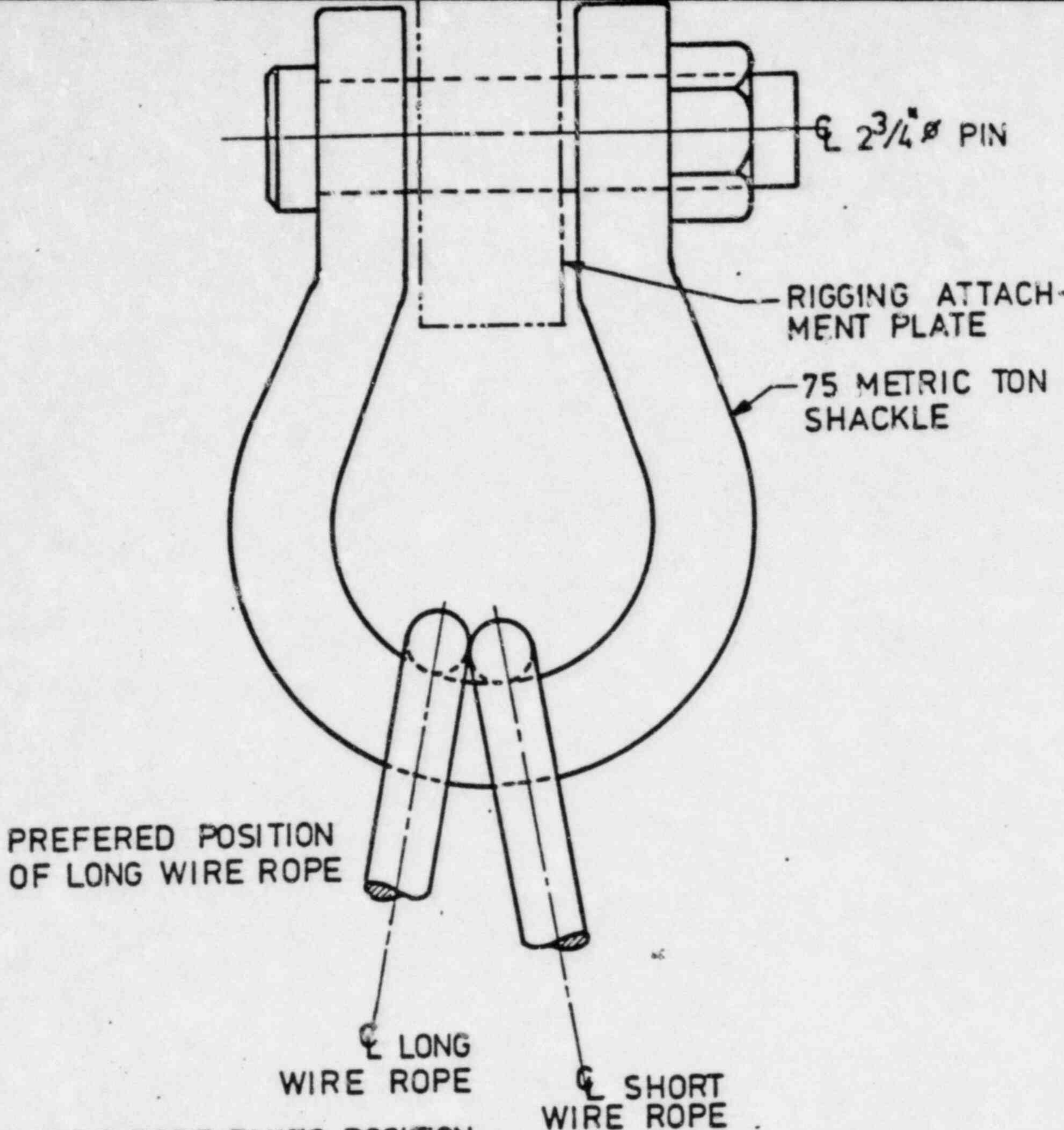


NOTE:

DIFFERENCE BETWEEN SLING LENGTHS GREATLY EXAGGERATED TO SHOW EQUALIZATION EFFECT. ACTUALLY THE DIFFERENCE IN SLING LENGTHS IS LESS THAN 0.123%.

EQUALIZATION ALONG LONGITUDINAL DIRECTION

ENCLOSURE 1



LONG WIRE ROPE TAKES POSITION IN SHACKLE AFTER SHORT WIRE ROPE IS POSITIONED. CURVATURE OF SHACKLE FORCES THIS ROPE TO POSITION ITSELF IN A MANNER THAT REQUIRES ADDITIONAL LENGTH, THUS SERVING TO EQUALIZE THE LOAD.

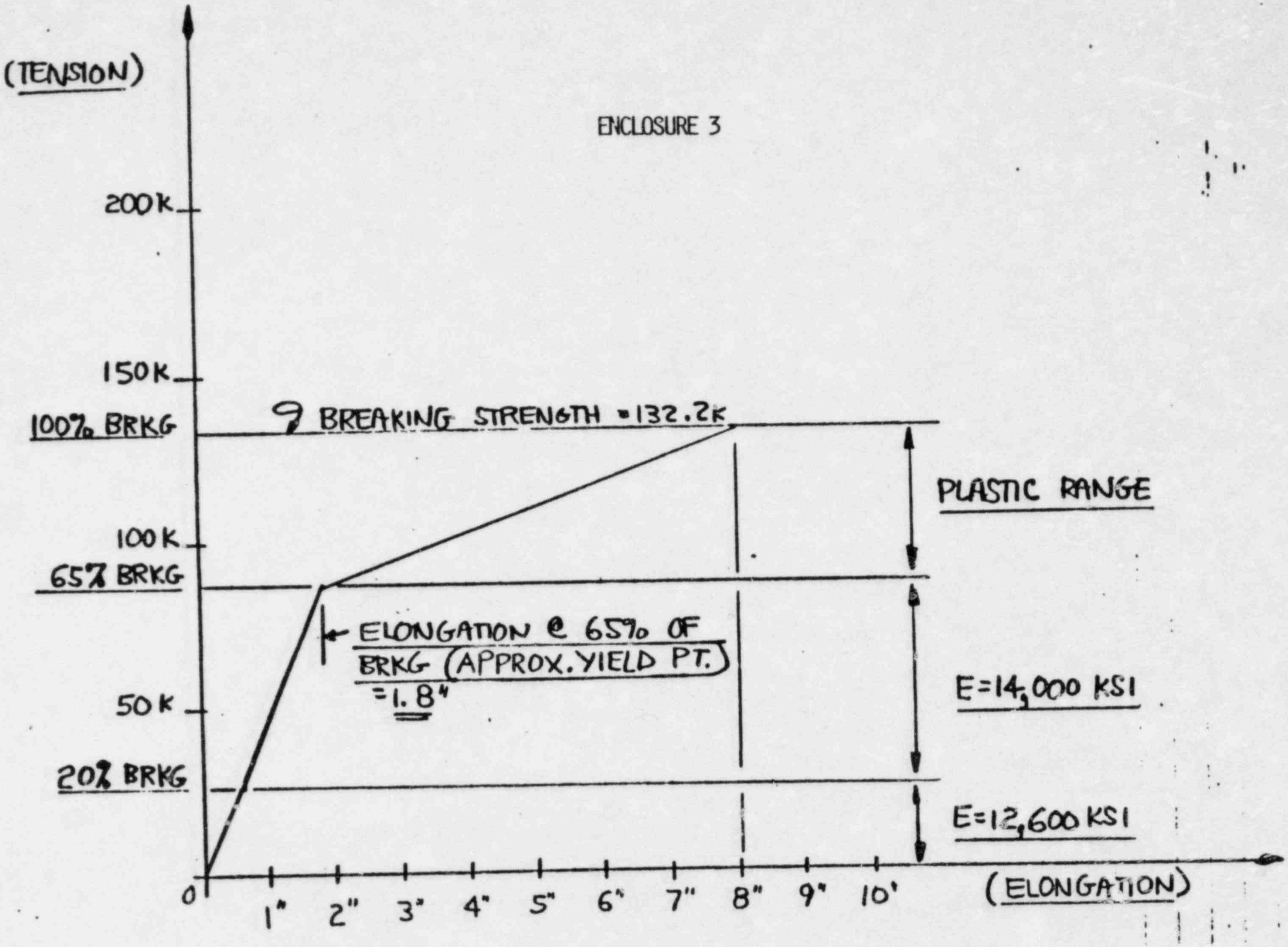
SHORT WIRE ROPE ASSUMES PREFERED POSITION IN SHACKLE CLOSEST TO ATTACHMENT POINT AT OTHER END OF ROPE.

NOTE: BOTH ROPES ARE WITHIN ± 1/8" IN LENGTH

EQUALIZATION IN TRANSVERSE DIRECTION

ENCLOSURE 2

ENCLOSURE 3



FORCE-ELONGATION CURVES FOR MISSLE SHIELD 1¼"Φ WIRE ROPE

Rigging Industry Standards for Safety Factors and Load Distribution to Multiple Legged Slings

No governing or nationally recognized code, such as those prepared by AISC, AWS or ASME, is available to provide detailed rules for rigging design. Information is available in the form of standards, independently written reference books, and vendor criteria, which provide basic guidelines. The guidelines are generally vague, rather simplified, and are based on successful past practice rather than rigorous testing or sophisticated analytical treatment.

The following has been abstracted from this information as it relates to factors of safety and distribution of loads to slings.

1. <u>ANSI B30.9-1971 - Slings</u>

From Section 9-2.2.1, Factor of Safety:

"The factor of safety for rope slings of all grades shall be a minimum of five (5). Features which affect the rated capacity of the sling and which shall be considered in calculating the factor of safety are:

a. Nominal wire rope breaking strength.
b. Splicing or end attachment efficiently.
c. Number of parts of rope in sling.
d. Type of hitch, e.g., straight pull, choker hitch, or basket hitch.
e. Angle of loading.
f. Diameter of curvature around which the sling is bent."

From Introduction, General Section:

"The standards committee fully realizes the importance of proper factors of safety, minimum or maximum sizes and other limiting dimensions of wire rope and their fastenings, sheaves, drums and similar equipment covered by the Standard, all of which are closely connected with safety. Safe sizes, strengths, and similar criteria are dependent on many different factors, often varying with the installation and uses. These factors also depend on the condition of the equipment or material; on the loads; on the acceleration, or speed of the ropes, sheaves or drums; on the type of attachments; on the number, size and arrangement of sheaves, or other parts; on weather, and other atmospheric conditions tending toward corrosion, or wear; and on so many variable factors that must be considered in each individual case. The rules given in the Standard must be interpreted accordingly and judgement used in determining their application."

2. ANSI B30.2.0-1976, Safety Standards for Cableways, Cranes, Derricks, Hoists, Hooks, Jacks and Slings
2-1.11.2 Ropes

"The hoisting ropes shall be of a recommended construction for crane service. The total load (rated load + load blocks weight) divided by the number of parts of rope shall not exceed 20% of the nominal breaking strength of the rope."

3. Rigger's Handbook - Form 2008-2 - Broderick &. Bascom Rope Co.

- "The factor of safety applying to a wire rope installation, may be defined as the ratio of the ultimate strength of the rope, to the actual load that has been imposed upon it by service conditions."
- "The working load on a wire rope will vary depending upon the application, from approximately a safety factor of 3 to perhaps 12 or more. However, for general hoisting service, a safety factor of 5 usually is adequate for a preliminary determination of the rope size.

4. Wire Rope Users Manual - American Iron and Steel Institute - 2nd Edition, 1981

"Design Factors" (safety factors)

"The design factor is defined as the ratio of the nominal strength of a wire rope to the total load it is expected to carry. Hence, the design factor that is selected plays an important part in determining the rope's service life. Excessive loading, whether continuous or sporadic, will greatly impair its serviceability. Usually, the choice of a certain rope size and grade will be based on static loading and, under static conditions, it is sufficient for its task. However, where a machine is working and dynamic loads are added to the static load, it is quite possible to exceed the material's elastic limit."

"As was noted in the earlier discussion, a "common" design factor is 5. Figure 60, The Wire Rope Relative Service Life Curve, shows how the service life is reduced as operating loads are increased. A change in the design factor from 5 to 3 decreases its life expectancy index from 100 to 60 - a drop of 40%!" (See attached Figure 60 on page 7 of 9.)

5. Macwhyte Wire Rope - Catalog G-18

"In the case of a given piece of equipment using wire rope, the overall economy and efficiency of the operation determines the relative expendability or useful life of the rope. This means that the wire rope is operated at a higher load on some types of equipment than on other types."

"In addition, the load can vary, within limits, with conditions present on individual installations."

"From this it follows that no fixed or arbitrary values for working load can be properly applied to all of the many classifications of service to which wire rope is subjected."

"Working loads for wire rope, depending upon how it is used, may vary from ½ to 1/12 of the strength of the rope. In general, for rough estimating, a maximum working load of 1/5 of the strength is commonly used . . ."

6. National Safety Council Data Sheet 380

Safety Factor

"When one end of a single rope sling is attached to the hook of a crane and the other end is attached to the load such as by a hook, the recommended load is not greater than one-fifth of the breaking strength of the rope providing the method of attachment develops 100 per cent of the breaking strength of the rope. If the efficiency of the attachment is less than 100 per cent, then the safe load limit can be found by using the following equation:

$$S = \frac{B \times E}{5^*}$$

S = safe load limit
B = breaking strength
E = efficiency of attachment

* Safety factor for wire rope slings under ordinary conditions of use, as adopted by the Wire Rope Technical Board."

Types of Slings

- "Two, three, or four single-leg slings make up a bridle sling. The safe lifting capacity depends on the number of legs and the angle formed by the legs. The capacity of a two-leg sling with each leg vertical is twice the load for a similar single leg vertical lift. A basket hitch, made by attaching one end of a single rope sling to the crane hook and passing the sling around the load and then attaching the other end to the crane hook, has equal capacity when both legs form a U, providing the minimum radius of bend in the rope at the point of load contact is five times the diameter of the rope."

- "The recommended load for a three-leg sling is 50 per cent more than the safe load limit for a two-leg sling at the same angle. Four a four-leg sling, the recommended load is 100 per cent more than that of a two-leg sling at the same angle."

7. Handbook of Rigging for Construction and Industrial Operations - 3rd Edition

- "Table I (not included) gives the safe working loads for the conventional wire-rope slings, iron-chain slings, alloy steel

slings, and braided slings. For manila-rope slings a safety factor of 10 is used. The loads are given for two-leg bridle slings at various angles. For three-way and four-way bridle slings these loads can be increased 50 per cent and one hundred per cent, respectively."

- "Of course, slings should be inspected periodically and condemned when found in an unsafe condition. A few broken wires do not perceptibly weaken the sling unless located near the throat of a socket, in which case they may indicate fatigue of the metal of the rope. If crushed not too severely the strands can be hammered back into shape by means of a wood mallet and a wood block. Slings, regardless of type, should be protected from corrosion and from contact with injurious chemicals. With reasonable care a sling should last indefinitely and should be one of the safest parts of the hoisting equipment."

8. Rigging Manual-Construction Safety Association of Ontario - 1st Edition October, 1975

Safety Factors:

"In its simplest form the Factor of Safety is defined as:"

$$\text{Factor of Safety} = \frac{\text{Catalog Breaking Strength of the rope}}{\text{Maximum Safe Working Load}}$$

"For rigging ropes the minimum acceptable factor of safety is 5 . . ."

"The factor of safety accounts for:

- Reduced capacity of the rope below its stated breaking strength due to wear, fatigue, corrosion, abuse, and variation in size and quality.
- End fittings and splices which are not as strong as the rope itself.
- Extra loads imposed by acceleration and inertia (starting, stopping, swinging and jerking of the load).
- Inaccuracies in the weight of the load.
- Inaccuracies in the weight of the rigging."

The above is not a complete list.

Slings:

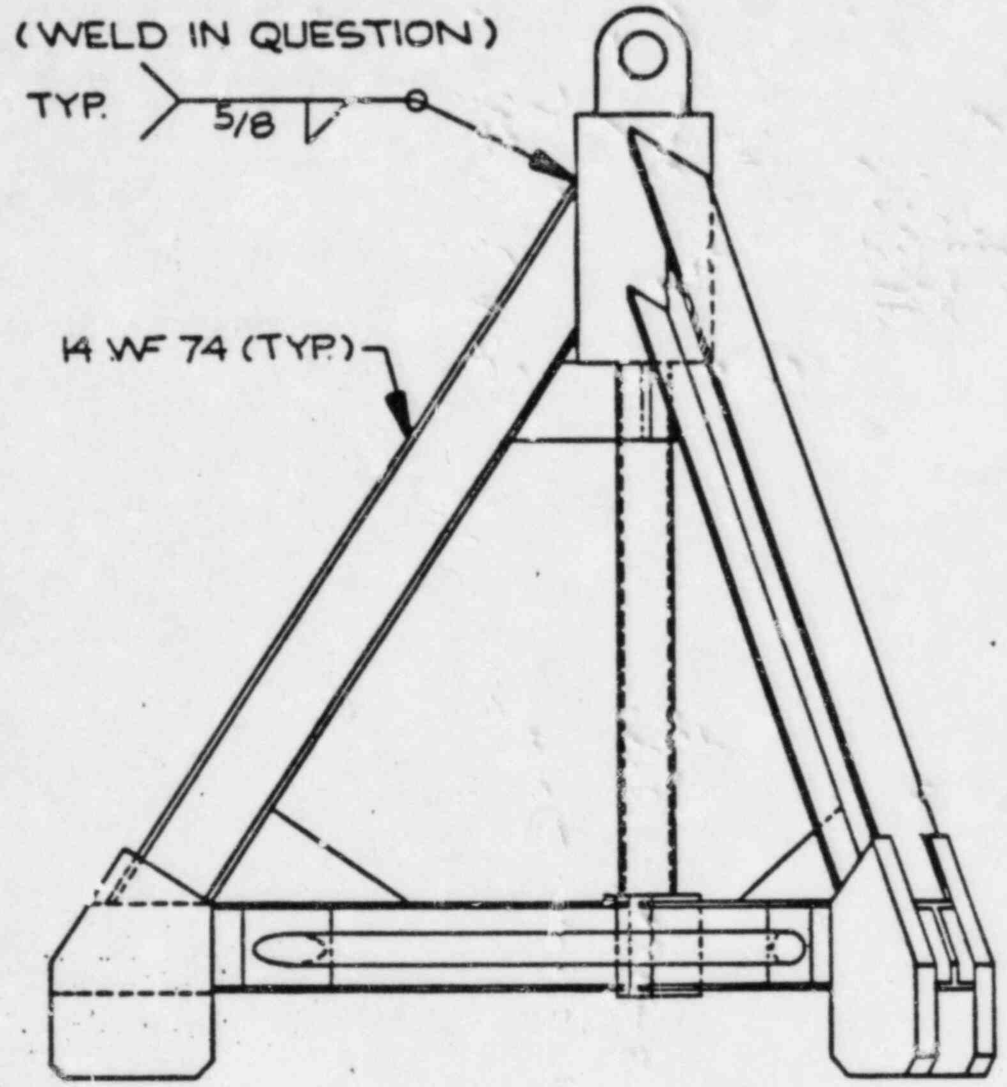
"Because of the severe service expected of slings, errors in determining load weight, and the effect of sling angle on the loading, it is recommended that all safe working loads be based on factor of safety of at least 5:1."

Bridle Hitch

"Two, three or four single hitches can be used together to form a bridle hitch for hoisting an object that has the necessary lifting lugs or attachments. They can be used with a wide assortment of end fittings. They provide excellent load stability when the load is distributed equally among the legs, when the hook is directly over the center of gravity of the load and the load is raised level. In order to distribute the load equally it may be necessary to adjust the leg lengths with turnbuckles. The use of a bridle sling requires that the sling angles be carefully determined to ensure that the individual legs are not overloaded."

"Unless the load is flexible, it is wrong to assume that a 3 or 4 leg hitch will safely lift a load equal to the safe load on one leg multiplied by the number of legs because there is no way of knowing that each leg is carrying its share of the load. When slings having more than 2 legs and a rigid load, it is possible for two of the legs to take practically the full load while the others only balance it."

NOTE: EXCERPTED FROM B&W DWG. 128733E, REV. 0



HEAD & INTERNALS HANDLING
FIXTURE ASSEMBLY
(TRIPOD)

FIGURE 4

APRIL 1983

memo from R. W. JACKSON

TO: JWT

This is the calc.
which covers the
drop of one shield
on another and
the test load assembly
back onto the floor.
It is approved for release
outside Bechtel.

RWJ
4/29/83

Calc. No. C-1-5

1.) Note 1 on sheet 25 indicates that the supporting column capacities were not evaluated. The column capacities were evaluated in a separate calculation (No. C-1-11) and determined to be adequate.

2.) Note 6 on sheet 26 indicates that no drop on the columns is considered. This statement should not be a problem since the calculations show that the floor will collapse for all lifts except the 6" load test assembly lift. For this lift, a direct drop on a column could not occur if the assembly is located per the design drawings.

CALCULATION COVER SHEET

PROJECT TMI JOB NO. 13587 CALC. NO. C-1-5

SUBJECT LOAD DROP ANALYSIS

ORIGINATOR MARWAN DAYE DATE 12/22/82

CHECKER F. Akkoush DATE 12/22/82 NO. OF SHEETS 28 ⊗

RECORD OF ISSUES

NO.	DESCRIPTION	BY	DATE	CHKD	DATE	APPRD	DATE	ACCEPT-ANCE	DATE
0	FOR PROJECT USE	M.D	12/22/82	F.A	12/22/82	[illegible]	12/22/82	[illegible]	1/14/83

☐ PRELIMINARY CALC.
☐ SUPERSEDED CALC.
☐ COMMITTED PRELIMINARY CALC.
☒ FINAL CALC.

Note:
This calculations are subject to the assumptions and limitations stated on sheets 25 and 26.

⊗ Includes cover sheet and attachment

GPD-2704 Rev. 10/78 (ED-11)

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Baye DATE 12/8/82 CHECKED E. Akkaash DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg. El 347'-6" SHEET NO. 1

Purpose:

The purpose of this calc. is to determine any possible damage to the containment floor at elevation 347'-6" Due to accidental drop of missile shield panels while being lifted. Also to determine the maximum height possible to lift the Reactor head and 220 Ton Test load such that an accidental drop would not damage the containment floor at elev 347'-6".

References:

1- Bechtel DWGS

13587 2-COP-1301 Rev 1

2-SK-P-45 Rev A

2-SK-P-46 Rev A

2- Burns & Roe DWGS.

4176, 4177, 4156, & 4190

3. BC TOP 9A Rev. 2

Attachment 1

IOM E. Sutton to E. Thomas 12/20/82

Weight & Dimensions of Reactor Head.

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/8/82 CHECKED E. Akkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg El. 347'-6" SHEET NO. 2

Approach:

A- For lifting of missile shield panels, three floor areas were considered. (Ref. DWG 2-SK-P-45)

1- When the lift is over the reactor cavity which is covered by other missile shield panels.

2- When the lift is over the floor directly south of the reactor cavity where the floor consists of Removable steel cover over Hatch.

3- When the lift is over the floor South-West of the reactor Cavity where the floor consists of 1'-1" thick concrete floor.

B- For lifting of Reactor head, Areas 2 & 3 of A above were Considered.

GPD-2706 8/76 (ED-69)

CALCULATION SHEET

ORIGINATOR M. Dwyer DATE 12/8/82 CALC. NO. C-1-5 REV. NO. 0

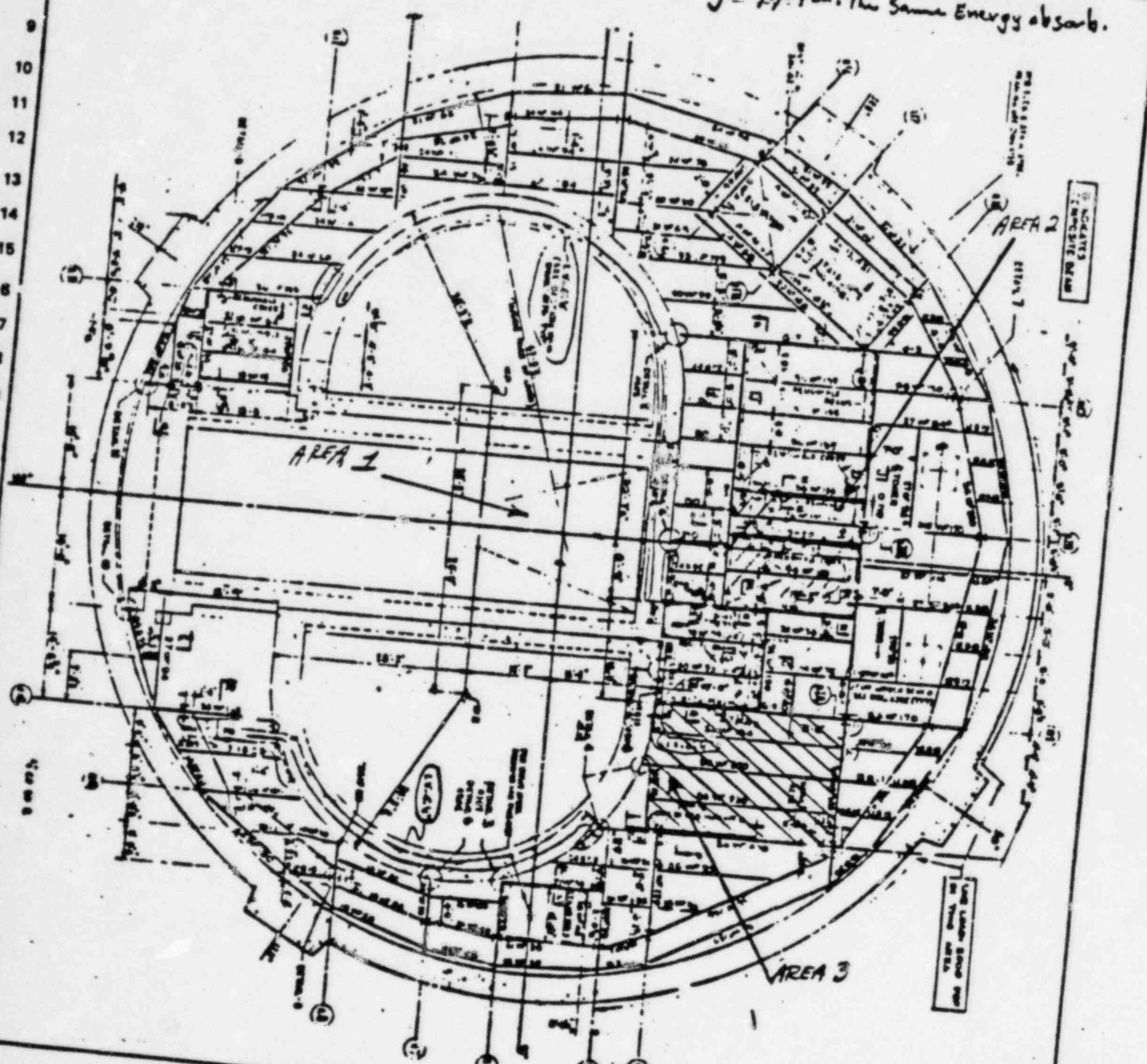
PROJECT TMI CHECKED E. Akkoush DATE 12/22/82

SUBJECT Load Drop Reactor Bldg EL 347-6 JOB NO. 13587

SHEET NO. 3

C - For lifting of the test load, Area 2 of A above is considered

D - other areas were assumed to be represented by the above considered areas. These other areas had smaller beam sections and shorter spans, thus having approx. the same Energy absorb.



BECHTEL

CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/18/82 CHECKED E. Alkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 4

Missile Data:

1. Concrete panels 3' x 6' x 29' (Ref. Burns & Roe DWG 4156)

Concrete weight = 150 #/C.F.

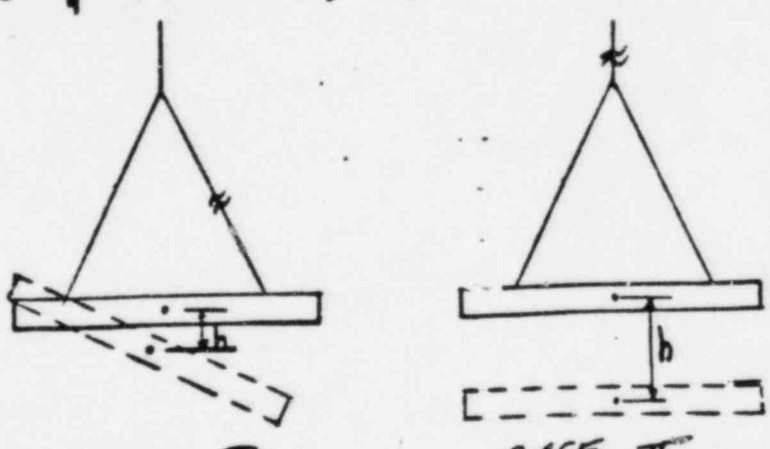
Missile weight $= 3 \times 6 \times 29 \times \frac{150}{1000} = 78\ K$

Missile Mass $M_m = \frac{78}{32.2} = 2.422\ K\text{-}Sec^2/FT$

Missile Velocity $V_s = \sqrt{2gh}$

Depending on the location of the missile at the time it drops, the velocities are:

	CASE I		CASE II		Affected Area
a)	h = 12.2'	Vs = 28 fps.	h = 24.4'	Vs = 39.6	Area 2
b)	h = 0.75'	Vs = 7 fps.	h = 1.5'	Vs = 9.8	Area 1
c)	h = 3'	Vs = 14 fps.	h = 6'	Vs = 19.7	Area 3

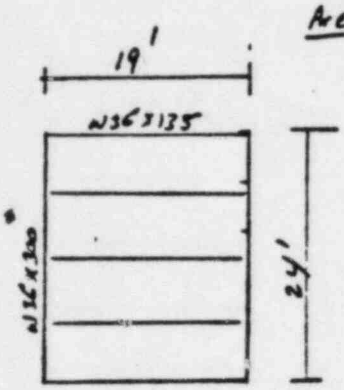


CASE I CASE II

GPD-2706 8/78 (ED-69)

Target Data

Three types of Floor Area systems are considered to represent a target, and are described and idealized as follows:



* Assumed to replace ℄ Girder.

IDEALIZED FLOOR SYSTEM

Area 2 - Series of W36x135 steel sections approximately 6' appart and spaning 19 feet between plate Girders. The W36 sections are supporting a removable steel cover consisting of Top and bottom checkered plates sandwitched between there are C & I sections

$M_c \approx 0$

Area 3 - Series of W36x230 steel sections approximately 5' appart and spaning 27 feet. The W36 Section are supporting 13" thick Reinforced

IDEALIZED FLOOR SYSTEM

BECHTEL

CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/8/82 CHECKED E. Alkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 6

Target Data (contd.)

Area 1 - a missile shield in place over the reactor forming a 3' thick Reinforced concrete slab spaning approximately 27' over the reactor cavity.

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/9/82 CHECKED F. Akkoak DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 7

Missile over floor System 1 (Energy Balance)
BC TOP-9A Rev 2.

Drop Case I-a $h = 12.2'$, $V_s = 28$ fps.

The required target strain energy to absorb impact energy

$$E_s = \frac{M_m^2 V_s^2}{2(M_m + M_e)}$$

$$E_s = \frac{(2.422)^2 (28.)^2}{2(2.422+0)} \times 12 = 11393 \text{ k-in}$$

Resistance-Displacement for W36x135 w/center load

$$R_m = \frac{4 M_u}{L} = \frac{8 I f_{dy}}{L d} = \frac{8 \times 7820 \times 36 \times 1.2}{(19 \times 12)(36)}$$

$$R_m = 329 \text{ k}$$

$$x_e = \frac{R_m L^3}{48 E I} = \frac{329 \times (19 \times 12)^3}{48 \times 30{,}000 \times 7820} = 0.3463 \text{ in}$$

Allowable Drop height

$$\frac{E_s}{x_e R_m} + \frac{1}{2} = \mu \leq 10$$

$$E_s = 9.5(x_e R_m) = 1082 k'$$

$$\frac{(2.422)^2 V_s^2}{2(2.422+0)} \times 12 = 1082$$

$V_s = 8.6$ fps $h = 14''$

Strain Energy for elastic response $E_e = \frac{1}{2} R_m x_e = 114$ k-in $< 23{,}904$ k-in

then, the structural response is elasto-plastic and the required ductility ratio is computed as $\mu = \frac{E_s}{x_e R_m} + \frac{1}{2} = 100.5 > 10$

The floor will not withstand the missile Drop. NG.

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Dagh DATE 12/9/82 CHECKED E. Alkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 8

Missile over Floor System :

Drop Case II _ a $h = 24.4'$, $V_s = 39.6$ fps

the missile will drop flat either over 5-W36X135, or over 2-W36X300. both cases will be considered:

1 - Drop over 5- W36X135

the mass of the missile is assumed to equally distribute over the five beams : $M_m = \frac{2.422}{5} = 0.484$

The required Target Strain Energy to absorb impact Energy : $E_s = \frac{(0.484)^2 (39.6)^2}{2(0.484 + 0)} \times 12 = 4554$ k-in

Resistance - Displacement (from previous case)

$R_m = 329$ k

$X_e = 0.3463$ in

$\mu = \frac{E_s}{X_e R_m} + \frac{1}{2} = 40.5 > 10$ N.G.

Floor will not withstand the drop.

Allowable Drop height

$\frac{E_s}{X_e R_m} + \frac{1}{2} = \mu \leq 10$

$E_s = 9.5(X_e R_m) = 1082$ k"

$\frac{(0.484)^2 V_s^2}{2(0.484+0)} \times 12 = 1082$

$V_s = 19$ fps. $h = 70"$

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/9/82 CHECKED F. Akloush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 9

2- Drop over 2- W36x300

the mass of the missile is assumed to equally distribute over the two beams: $M_m = \frac{2.422}{2} = 1.211$

the required target strain Energy to absorb impact

Energy $E_s = \frac{(1.211)^2(39.6)^2}{2(1.211+0)} \times 12 = 11394$ k-in

Allowable Drop height

$\frac{E_s}{x_e R_m} + \frac{1}{2} = \mu \leq 10$

$E_s = 9.5(x_e R_m) = 3555$ k"

$\frac{(1.211)^3 V_s^2}{2(1.211+0)} \times 12 = 3555$

$V_s = 22$ fps. $h = 91$"

Resistance - Displacement for W36x300 w/center load.

$R_m = \frac{4M_u}{L} = \frac{8 I f_{dy}}{L d} = \frac{8 \times 20300 \times 36 \times 1.2}{(12 \times 24) \times (36)} = 676.7$ k

$X_e = \frac{R_m L^3}{48EI} = \frac{676.7 \times (24 \times 12)^3}{48 \times 20300 \times 30{,}000} = 0.553$ in

strain Energy for elastic response $E_e = \frac{1}{2} R_m X_e = 187$ k-in < 7771 k-in

then, structural response is elasto-plastic and the required ductility ratio is: $\mu = \frac{E_s}{R_m X_e} + \frac{1}{2} = 30.9 > 10$ N.G

Floor will not withstand the Drop.

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Dayes DATE 12/10/82 CHECKED E. Akbari DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 10

Missile Shield Ultimate Capacity

As simply supported Beam.

$l = 29 - 2 = 27'$ $A_s = 12 - \#11 \text{ Bars} = 18.72 \text{ in}^2$

$t = 3'$, $d = 32"$

$b = 6'$

$M_U = 4 d A_s = 4 \times 32 \times 18.72 = 2396.2$ K-FT.

$R_m = \dfrac{4 M_U}{l} = \dfrac{4 \times 2396.2}{27} = 355$ K.

$X_e = \dfrac{R_m l^3}{48 E I} = \dfrac{355 \times (27 \times 12)^3}{48 \times 5000 \times \frac{(6 \times 12) \times (32)^3}{12}} = 0.256$ in

$I = I_g$ (conservative)

For missile shield drop over another missile shield

Drop case I-b $h = 0.75$, $V_s = 7$ fps.

Required Target $E_s = \dfrac{M_m^2 V_s^2}{2(M_m + M_e)} = \dfrac{(2.432)^2 (7.)^2}{2(2.432 + \frac{41.9 \times 12}{1000})} \times 12 = 590$ k-in

Where $M_e = (6 \times 12)(3 \times 12 + 36) \times \dfrac{0.0868 \times 36}{386.4} = 41.9$ $\frac{\text{lb-sec}^2}{\text{in}}$

strain Energy for elastic response

$$E_e = \frac{1}{2} R_m x_e = \frac{1}{2}(355)(0.256) = 45 < 590 \text{ k-in}$$

Response is elasto-Plastic, Required Ductility

ratio $\mu = \dfrac{E_s}{R_m x_e} + \dfrac{1}{2} = 7 < 10$ ok

Drop Case II-6 $h = 1.5'$, $V_s = 9.8$ fps.

Required Target $E_s = \dfrac{M_m^2 V_s^2}{2(M_m + M_e)} = \dfrac{(2.422)^2 (9.8)^2}{2\left(2.422 + \frac{188.7 \times 12}{1000}\right)} \times 12$

Where $M_e = (6 \times 12)(27 \times 12) \times \dfrac{0.0868 \times 36}{386.4} = 188.7 \ \frac{\text{lb-sec}^2}{\text{in}}$

$E_s = 721.5$ k-in

Required Ductility Ratio for elasto-Plastic response

$$\mu = \frac{721.5}{355 \times 0.256} + \frac{1}{2} = 8.5 < 10$$

OK

BECHTEL

CALCULATION SHEET

CALC. NO. C·1·5 REV. NO. 0

ORIGINATOR M Dange DATE 12/10/82 CHECKED E. Akbous DATE 12/12/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 12

Missile over Floor System 2

Drop Case I – C $h = 3'$, $V_s = 14$ fps.

The required Target strain Energy to absorb impact Energy

$$E_s = \frac{(2.422)^2 (14)^2}{2\left(2.422 + \frac{12.1 \times 12}{1000}\right)} \times 12 = 2687 \text{ k-in}$$

where $M_e = (72+13)(36+13) \cdot \frac{0.0868 \times 13}{386.4} = 12.1$ #-sec²/in

Resistance – Displacement for a beam W/Center load. (W36 x 230)

$$R_m = \frac{4 M_u}{L} = \frac{8 I f_{dy}}{L d} = \frac{8 \times 15000 \times 36 \times 1.2}{(27 \times 12)(36)}$$

$R_m = 444.$ k (connection ultimate capacity 450k based on 20 - 7/8 ϕ A325 Bolts.)

$$x_e = \frac{R_m L^3}{48 E I} = \frac{444 \times (27 \times 12)^3}{48 \times 30{,}000 \times 15000} = 0.7 \text{ in}$$

strain Energy for Elastic responce $= \frac{1}{2} R_m x_e = 155$ k-in < 2687

Then, the structural response is Elasto-Plastic

and the required ductility Ratio is computed

as $\mu = \frac{E_s}{X_e R_m} + \frac{1}{2}$

$\mu = 9.2 < 10$ <u>OK</u>

In addition, the main W36 x 300 beam response will Reduce the ductility ratio.

Thus, the floor beam will withstand the impact.

Missile over Floor System 2

Drop Case II-C $h = 6'$, $V_s = 19.7$ fps

the missile will Drop flat either over 5 - W36x230, or over 2 - W36x300. both cases will be Considered:

1- Drop over 5 - W36x230

the mass of the missile is assumed to equally distribute over the five beams: $M_m = \frac{2.422}{5} = 0.484$.

The required target Strain Energy to absorb impact

$$\text{Energy: } E_s = \frac{(0.484)^2 (19.7)^2}{2\left(0.484 + \frac{40.2 \times 12}{1000}\right)} \times 12 = 564 \text{ k-in}$$

$$\text{where } M_e = (72+13)\left(\tfrac{27}{2} \times 12\right) \cdot \frac{0.0865 \times 13}{386.4} = 40.2$$

Resistance - Displacement (From Previous Case)

$R_m = 444$ k { connection ultimate capacity 450^k }.
$X_e = 0.7$ in { based 450^k based on 20 - 7/8"φ A325 Bolts) }

Strain Energy for elastic response $= \frac{1}{2} R_m X_e = 155$ k-in < 564

then, the Structural response is elasto-plastic, and the required Ductility Ratio is: $\mu = \frac{E_s}{R_m X_e} + \frac{1}{2} = 2.3 < 10$ OK

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Dinge DATE 12/10/82 CHECKED E. Akbust DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 14

2 - Drop over 2 - W36 X300

the mass of the missile is assumed to equally distribute over the two beams ; $M_m = \frac{2.422}{2} = 1.211$

The required target strain Energy to absorb impact

$$\text{Energy} \quad E_s = \frac{(1.211)^2 (19.7)^2}{2\left(1.211 + \frac{40.2 \times 2}{1000}\right)} \times 12 = 2016 \text{ k-in}$$

$$\text{where} \quad M_e = (72+13)\left(\tfrac{27}{2} \times 12\right) \times \frac{0.0868 \times 13}{386.4} = 40.2$$

Resistance - Displacement for W36 x 300 w/center load

$$R_m = \frac{4 M_u}{L} = 676.7 \text{ k}$$

$$X_e = \frac{R_m L^3}{48EI} = 0.553 \text{ in}$$

{connections ultimate capacity 450 k based on 20 - 7/8" ϕ A325 bolts}

Strain Energy for elastic response $E_e = \frac{1}{2} R_m X_e = 187 < 2016$ k-in

then, the structural response is elasto-plastic and the required ductility ratio is : $\mu = \frac{E_s}{X_e R_m} + \frac{1}{2} = 5.9 < 10$

OK

CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/13/82 CHECKED E. Alkash DATE 12/27/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 15

Reactor Head.

Determine Maximum safe lift height For Reactor Head.

See Attachment 1

Reactor Head weight = 170 Tons = 340 k

Reactor Head Mass $= \frac{340}{32.2} = 10.56$ k-sec²/FT.

Reactor Head Diameter ≈ 17'

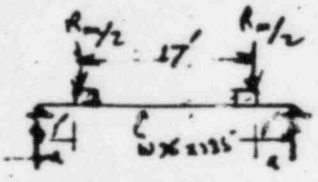
1- over Floor system 1 beams W36 x135

Drop is assumed over Three beams.

∴ missile mass per beam $M_m = \frac{10.56}{3} = 3.52$

For Ductility Ratio of 10

$$\frac{E_s}{X_e R_m} + \frac{1}{2} = 10$$



$$\frac{R_m}{2} = \frac{M_u}{a} = \frac{2 I f_{dy}}{a d} = \frac{2 \times 7800 \times 36 \times 1.2}{12 \times 36} = 1564 \text{ K. (Bending)}$$

$\frac{R_m}{2} = 36 \times 35.55 \times 0.598 \times 1.2 = 918$ k (shear)

$M_u = \frac{R_m}{2} a$

$\Delta = \frac{\frac{R_m}{2} a}{24EI}(3L^2 - 4a^2)$

Connection capacity 450 k based on 20 - 7/8"φ A325 Bolts

connection capacity Governs.

use $R_m/2 = 400$ to account for Dead loads.

GPD-2706 8/76 (ED-69)

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/22/82 CHECKED E. Akkouk DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg. E 347'-6" SHEET NO. 16

$$X_e = \frac{400 \times 12}{24 \times 30{,}000 \times 7820}\left[3(19 \times 12)^2 - 4(12)^2\right] = 0.1325 \text{ in}$$

$$E_s = 9.5\,(X_e R_m) = 1007 \text{ k-in}$$

$$E_s = \frac{M_m^2 V_s^2}{2(M_m + M_c)} = \frac{(3.52)^2 V_s^2}{2(3.52 + 0)} \times 12 = 1007.$$

$$V_s = 6.9 \text{ f.p.s.}$$

$$h = \frac{V_s^2}{2g} = 0.74 \text{ FT}$$

$$\simeq 9 \text{ in}$$

CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Dayeh DATE 12/13/82 CHECKED E. Akkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 17

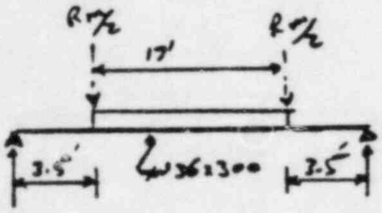
2. over floor system. 1 beam W36 x 300

Drop is assumed to affect one W36 x 300 $M_m = 10.56$

For Ductility Ratio of 10

$$\frac{E_s}{x_e R_m} + \frac{1}{2} = 10$$

$$E_s = 9.5 (R_m x_e)$$



$$R_{m/2} = \frac{2 \times 30300 \times 36 \times 1.2}{3.5(12) \times 36} = 1160 \text{ k} \quad \text{(Bending)}$$

$$R_{m/2} = 36 \times 36.72 \times 0.945 \times 1.2 = 1499 \text{ k (Shear)}$$

$R_{m/2}$ = 400k connection capacity (see sheet 15)

$$X_e = \frac{400 \times 3.5 \times 12}{24 \times 30{,}000 \times 20300} \left[3(24 \times 12)^2 - 4(3.5 \times 12)^2\right]$$

$$X_e = 0.278 \text{ in}$$

$$E_s = 9.5(2 \times 400 \times 0.278) = 2113 \text{ k·in}$$

$$E_s = \frac{M_m^2 V_s^2}{2(M_m + M_c)} = \frac{(10.56)^2 V_s^2}{2(10.56 + 0)} \times 12 = 2113$$

$V_s = 5.77$ FPS. $\quad h = \frac{V_s^2}{2g} = 0.52$ FT $= 6.$ in

CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Danze DATE 12/13/82 CHECKED E. Akkout DATE 12/22/82

PROJECT TMI JOB NO. 13587

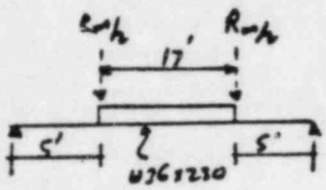
SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 18

3. Over Floor System 2 Beam W36x230

Drop is assumed over three beams.

∴ Missile mass per beam $M_m = \frac{10.56}{3} = 3.52$

For Ductility Ratio of 10



$$E_s = 9.5\,(R_m\, x_e)$$

$$R_m/2 = \frac{M_u}{a} = \frac{2 I f_{dy}}{a\, d} = \frac{2\times15000\times36\times1.2}{5\times12\times36} = 600 \text{ k (Bending)}$$

Governs.

$$R_m/2 = 36\times35.88\times0.761\times1.2 = 1180\text{ k}$$

$R_m/2 = 400$ k Connection Capacity (see sheet 15)

$$X_e = \frac{400\times5\times12}{24\times30,000\times15000}\left[3(27\times12)^2 - 4(5\times12)^2\right] = 0.67 \text{ in}$$

$$E_s = 9.5\,(2\times400\times0.67) = 5092 \text{ k-in}$$

$$E_s = \frac{M_m^2\, V_s^2}{2(M_m+M_e)} = \frac{(3.52)^2\, V_s^2}{2\left(3.52+\frac{45.6\times12}{1000}\right)}\times12 = 5092$$

Where $M_e = (17\times12+13)(6\times12)\times\frac{0.0868\times13}{386.4} = 45.6\ \frac{\text{lb-sec}^2}{\text{in}}$

$V_s = 16.7$ f.p.s. $\quad h = \frac{V_s^2}{2g} = \underline{\underline{4.33 \text{ FT.}}} = 52$ in.

CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Dayn DATE 12/13/82 CHECKED E. Akkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

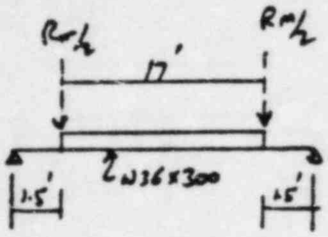
SUBJECT Load Drop Reactor Bldg. EL 347'-6" SHEET NO. 19

4 - over floor system 2 Beam W36X300

Drop is assumed to affect one W36X300

$M_m = 10.56$

For Ductility Ratio of 10



$$\frac{E_s}{x_e R_m} + \frac{1}{2} = 10 \Longrightarrow E_s = 9.5\,(x_e R_m)$$

$$R_m/2 = \frac{2 \times 20300 \times 36 \times 1.2}{1.5 \times 12 \times 36} = 2707 \text{ k. (Bending)}$$

$R_m/2 = 36 \times 36.72 \times 0.945 \times 1.2 = 1499$ k (shear)

$R_m/2 = 400$k connection capacity (see sheet 15)

$$X_e = \frac{400 \times 1.5 \times 12}{24 \times 20{,}300 \times 30{,}000}\left[3\,(20 \times 12)^2 - 4\,(1.5 \times 12)^2\right]$$

$X_e = 0.085$ in

$E_s = 9.5\,(2 \times 400 \times 0.085) = 646$ k-in

$$E_s = \frac{M_m^2 V_s^2}{2(M_m + M_e)} = \frac{(10.56)^2 V_s^2}{2\left(10.56 + \frac{137.5 \times 12}{1000}\right)} \times 12 = 646$$

where $M_e = (17 \times 12 + 13)^2 \times \frac{0.0868 \times 12}{336.4} = 137.5 \ \frac{\text{lb-sec}^2}{\text{in}}$

$V_s = 3.43$ fps. $h = \frac{V_s^2}{2g} = 0.183$ FT

$\approx 2.$ in

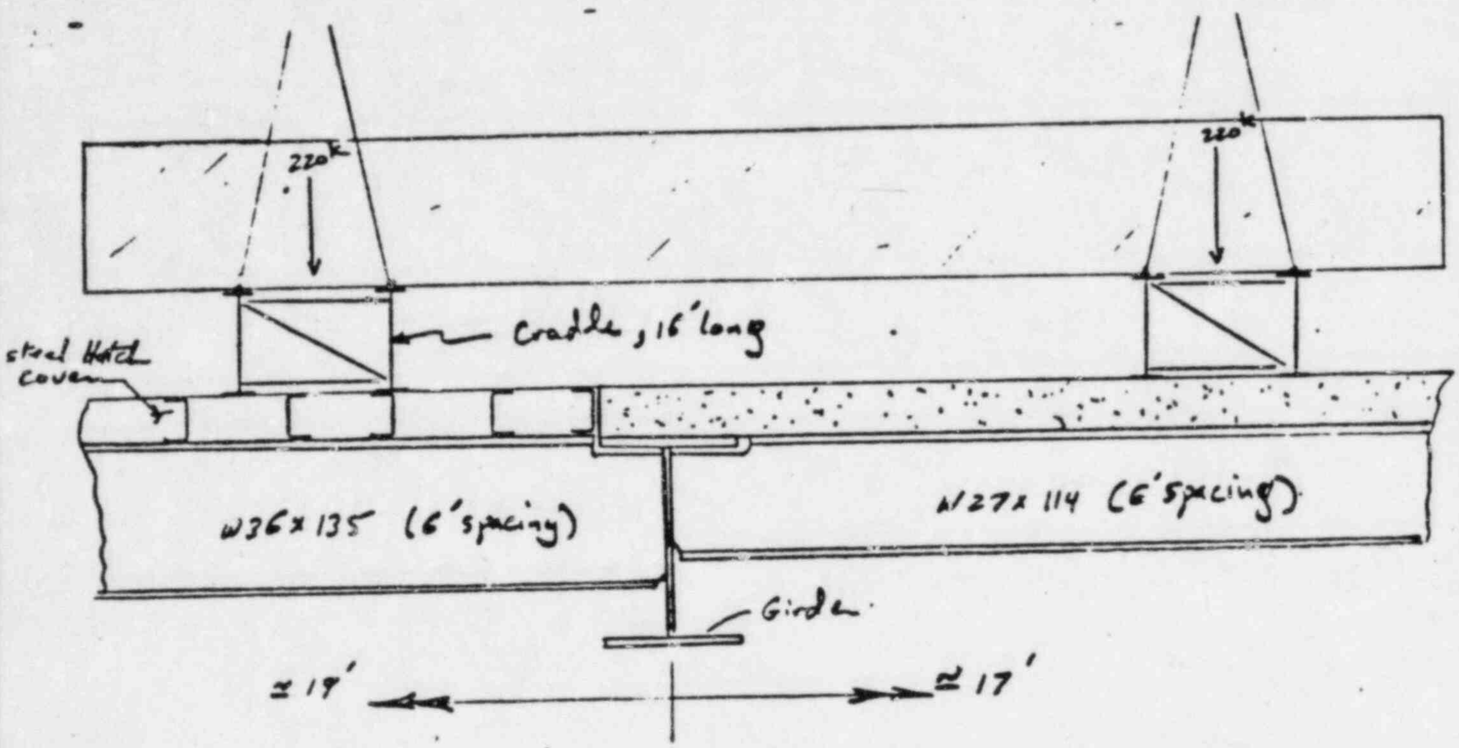
CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/16/82 CHECKED E. Alkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg El 347'-6" SHEET NO. 20



Approximate Arrangement of test load over floor at elevation 347'-6".

The lift of the load is limited so that each cradle is assumed to drop almost horizontally, such that half the load is assumed to affect a W-Section

Mc for steel hatch cover is neglected

Mc for 13" concrete slab = 12.1 lb-sec²/in

See 2-SK-P-46 for load test location

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/15/82 CHECKED E. Alkorsh DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg EL 347'-6" SHEET NO. 21

1 - over Hatch Area of Area 2 Floor System 1

Effective Droped Load per beam $= \frac{220}{2} = 110^{k}$

Effective Droped Mass $= \frac{110}{32.2} = 3.416$ k-sec²/FT

For Ductility Ratio of 10

$$\frac{E_s}{R_m X_e} + \frac{1}{2} = 10$$

$$E_s = 9.5\,(R_m X_e)$$

$$R_m = \frac{4\,M_U}{L} = \frac{8\,I\,f_{dy}}{L\,d} = \frac{8 \times 7820 \times 36 \times 1.2}{(19 \times 12) \times 36} = 329.3^{k}$$

329.3 < R_m for Connection Based on 20 - 7/8" ϕ A325 Bolts

$$X_e = \frac{R_m L^3}{48\,EI} = \frac{329.3 \times (19 \times 12)^3}{48 \times 30{,}000 \times 7820} = 0.346 \text{ in}$$

Required $E_s = 9.5\,(329.3 \times 0.346) = 1082.$ k-in

$$E_s = \frac{M_m^2 V_s^2}{2(M_m + M_e)} = \frac{(3.416)^2\, V_s^2}{2(3.416 + 0)} \times 12 = 1082$$

$$V_s = 7.3 \text{ f.p.s.}\,, \quad h = \frac{V_s^2}{2g} = 0.82 \text{ FT} \simeq 10 \text{ in}$$

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/16/82 CHECKED E. Albaush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg. El. 347'-6" SHEET NO. 22

2 - Over Concrete Area of Area 2 floor System 1

Effective Droped Mass = 3.416 $k\text{-}sec^2/FT$

For Ductility of 10

$E_s = 9.6\ (R_m\, x_e)$

$R_m = \dfrac{4M_u}{L} = \dfrac{8\, Z\, f_{dy}}{L\, d} = \dfrac{8 \times 4090 \times 36 \times 1.2}{(17 \times 12) \times 27} = 256.6\ K$

256.6 < R_m for connection Based on 20 - 7/8" A325 Bolts

$X_e = \dfrac{R_m L^3}{48EI} = \dfrac{256.6 \times (17 \times 12)^3}{48 \times 30{,}000 \times 4090} = 0.37$ in

Required $E_s = 9.5\ (256.6 \times 0.37) = 902$ k-in

$E_s = \dfrac{M_m^2 V_s^2}{2(M_m + M_e)} = \dfrac{(3.416)^2 V_s^2}{2\left(3.416 + \frac{12.1 \times 12}{1000}\right)} = \dfrac{902}{12}$

$V_s = 6.77$ f.p.s. , $h = 0.712$ ft.

$h = 8.5$ in

CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/16/82 CHECKED E. Akbash DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg El. 347'-6" SHEET NO. 23

Summary:

A- Missile Shield lift:

Area 1 over Reactor cavity

lift h = 1.5 FT. ok

Area 2 south of Reactor cavity

lift h = 24.4 FT NG
(Allowed lift h = 14")

Area 3 South-West of Reactor Cavity

lift h = 6 FT. ok

B- Reactor Head lift:

Area 1. over Reactor cavity

not Applicable

Area 2 south of Reactor Cavity

max lift ≃ 6 in

Area 3 South-West of Reactor Cavity

max lift ≃ 2 in

CALCULATION SHEET

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/16/82 CHECKED E. Albous DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg El 347-6" SHEET NO. 24

C - Test load lift

Area 2 only South of Reactor Cav.

Max lift = 0.7 FT

= 8. in

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/22/82 CHECKED E. Alkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg. EL 347'-6" SHEET NO. 25

Notes :

1- In the above computation, the supporting Columns Capacities were not evaluated.

2. Drop is postulated to hit the structural Elements at the center of span.

3. Beam/Columns Connections are checked to assure Elasto plastic behaviour of the beams.

4- Bolted Connection Capacities are computed based on assumed Twenty - 7/8" ϕ A325 Bolts capacity.

5- Columns Capacities should be evaluated and compared with Reactions computed in this calculations

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-5 REV. NO. 0

ORIGINATOR M. Daye DATE 12/22/82 CHECKED E. Akkoush DATE 12/22/82

PROJECT TMI JOB NO. 13587

SUBJECT Load Drop Reactor Bldg. El 347'-6" SHEET NO. 26

6 - No Drop on columns is considered.

7 - Ultimate moment of steel sections is computed as $M_u = \frac{8 I f_{dy}}{L d}$

where $f_{dy} = f_y \times 1.2$.

Ultimate moment is used in lieu of plastic moment Mp. this is assumed to compensate for the existing loads.

8 - Since the difference in elevations between 347'-6" Floor and 305'-0" Floor (42'-6") much exceeds any allowed drop height, it is expected that any missile that penetrates the 347'-6" Floor will damage the floors and equipment below.

9 - Static loads Due to Reactor head and Test load Frame on the floor had been checked by project Personnel. Per telecon M. Daye to E. Sutton.

GPD-61 C 2/75 (FORM G-3)

to calc. no. C-1-3

MEMORANDUM

"DON'T SAY IT — WRITE IT"

To G. Thomas / M. Daye

Location 1A-7

From E. Sutton

Date 12/20/82

Subject: Heavy Load Drop Analysis

The following information is forwarded for use in the Heavy Load Drop Analysis of the RV Head and rigging:

- Total weight of RV Head & rigging = 170 TONS
- O.D. of the RV Head flange - - - = 200 inches
- I.D. of the RV Head flange - - - = 153 inches
- The live load capacity for the 347'6" floor in the load drop area - - - - = 2000 psf (per Burns & Roe Dwg. no. 4177.)

EJS

KHC

memo from | R. W. JACKSON

TO: JWT

This is the calc for the 6" missile shield drop back onto the D-ring. It is approved for release outside Bechtel.

RWJ
4/29/83

Calc. No. C-1-10

1.) This calc. was performed in response to your request. It was assumed that the 6" drop of a missile shield was bounded by the 18" drop of a shield on another shield, performed in Calc. No. C-1-5. This calc. confirms our assumption.

CALCULATION COVER SHEET

BECHTEL

PROJECT T.M.I-2 JOB NO 15737 CALC. NO. C-1-10

SUBJECT CHECK IF RV MISSLE SHIELD BREAKS WHEN IT IS DROPPED FROM A HEIGHT OF 6"

ORIGINATOR William L. Siskos DATE 4/15/83

CHECKER MARWAN DAYE DATE 4/15/83 NO OF SHEETS 3

RECORD OF ISSUES

NO.	DESCRIPTION	BY	DATE	CHKD	DATE	APPRD	DATE	ACCEPT-ANCE	DATE
0	Issued for Project Use	WS	4/15/83	MD	4/15/83	[illegible]	4/27/83	[illegible]	4/29/83

- [ ] PRELIMINARY CALC.
- [ ] SUPERSEDED CALC.
- [ ] COMMITTED PRELIMINARY CALC.
- [x] FINAL CALC.

CALCULATION SHEET

CALC. NO. C-1-10 REV. NO. 0

ORIGINATOR William L Siskos DATE 4-15-83 CHECKED M Page DATE 4/15/83

PROJECT T. M. I JOB NO. 13587

SUBJECT Load Drop SHEET NO. 1

OBJECTIVE

THE PURPOSE OF THIS CALCULATION IS TO EVALUATE THE CAPABILITY OF A MISSILE SHIELD PANEL TO ABSORB THE ENERGY GENERATED FROM DROPPING THE PANEL THROUGH SIX INCH HEIGHT.

THE LOADS IMPOSED WOULD BE DUE TO THE PANEL'S OWN WEIGHT DROPPING IN A FLAT POSITION AND HITTING TWO END SUPPORTS.

VALUES FOR PARAMETERS USED IN THIS CALCU-LATION HAVE BEEN COMPUTED IN CALCULATION № 13587-C-1-5 DATED 1/14/83.

GPD-2706 8/76 (ED-69)

CALCULATION SHEET

CALC. NO. C-1-10 REV. NO. 0

ORIGINATOR William L. Siskos DATE 4-15-83 CHECKED M. Day DATE 4/15/83

PROJECT T.M.I-2 JOB NO. 15737

SUBJECT Load Drop SHEET NO. 2

CHECK IF RV MISSLE SHIELD BREAKS WHEN IT IS DROPPED FROM A HEIGHT OF 6"

Velocity $V = \sqrt{2gh} = 5.6745\ ^{ft}/_{sec}$

Energy = Weight of Missile × height

Weight = $6 \times 3 \times 29 \times .150 = 78^k$

Missile Mass $= \dfrac{78}{32.2} = 2.422\ ^{k \cdot sec^2}/_{ft}$

$M_u = 2396.2$ k-ft $L = 29 - 2' = 27'\text{-}0"$ CLEAR SPAN

$2396.2 = \dfrac{R_m L}{8}$ $R_m = 709.98^k$

$X_E = \dfrac{5 \cdot 709.98 \cdot (27 \times 12)^3}{384 \cdot 3{,}000 \dfrac{(6 \times 12) \times 32^3}{12}} = .3198"$

STRAIN ENERGY FOR STATIC RESPONSE = $709.98 \times .3198 = 227.05$ k"

Potential Energy to be absorbed = $78^k \times 6" = 468^{k"} = \frac{1}{2} \cdot 2.422 \times 5.6745^2 \times 12$

P.E > STRAIN ENERGY ∴ Response is Elasto-Plastic

$\mu = \dfrac{468}{227.05} + \frac{1}{2} = 2.56 < 10$ OK

SHEAR STRESS $= \dfrac{709.98}{2 \times 60 \times 32} = .184$ KSI

for Slabs $v_{all} = 4\sqrt{f'_c} = 4 \times \sqrt{5{,}000} = 282.8$ psi > 184 psi OK

MISSILE ALSO HAS #4 STIRRUPS

#4 STIRRUPS WITH VARIABLE SPACING WHICH STARTS @ 6" by SUPPORT AND 18" AT MIDDLE SPAN

CALCULATION SHEET

CALC. NO. C-1-9 REV. NO 0

ORIGINATOR Francis M Forbes Jr DATE 4-25-83 CHECKED C. IANNI DATE 4-29-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT MISSILE SHIELD RIGGING - WIRE ROPE LENGTH TOLERANCE ANALYSIS - CASE C SHEET NO. 1

OBJECTIVE

THE OBJECTIVE OF THIS CALCULATION IS TO DEMONSTRATE THAT, EVEN IF RELATIVELY LARGE ROPE LENGTH DIFFERENCES ARE ASSUMED A FACTOR OF SAFETY OF AT LEAST 5 IS MAINTAINED FOR EACH OF THE 1¼ INCH DIAMETER WIRE ROPES. THE WIRE ROPES FORM A PAIR OF TWO-LEG BRIDLES USED TO LIFT THE REACTOR AND PRESSURIZER MISSILE SHIELDS. THIS OBJECTIVE WILL BE DEMONSTRATED USING BASIC GEOMETRY TO ANALYZE THE ROTATION OF THE MISSILE SHIELD IF ROPES OF DIFFERENT LENGTHS ARE USED TO LIFT THE SHIELD. (SEE PLAN SH. 3)

ASSUMPTIONS

1. ASSUME THERE ARE TWO DIFFERENT ROPE LENGTHS (TWO SHORT ROPES AND TWO LONG ROPES)

2. ASSUME BOTH SHORT ROPES ARE ON THE SAME SIDE OF THE MISSILE SHIELD (SEE PLAN VIEW ON SH. 3 FOR ROPE ORIENTATION)

3. WIRE ROPE IS 6x37 CLASS, IWRC, IMPROVED PLOW STEEL, WITH A MINIMUM BREAKING STRENGTH OF 66.1 TONS. (PER DWG. 2-COP-1302, REV. 2)

4. THE REACTOR MISSILE SHIELD WEIGHS 41 TONS.

5. MISSILE SHIELD IS A RIGID BODY.

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-9 REV. NO. 0

ORIGINATOR Francis M Fo:kuyf DATE 4-25-83 CHECKED C. IANNI DATE 4-29-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT SHEET NO. 2

REFERENCES:

1. SMIRNOFF, MICHAEL V., MEASUREMENTS FOR ENGINEERING AND OTHER SURVEYS, PRENTICE-HALL (1961)

2. DRAWINGS:

   a) 2-COP-1302, RCTR BLDG POLAR CRANE LOAD CELL AND MISSILE SHIELD RIGGING, AND MISSILE SHIELD STORAGE SUPPORTS. (Rev. 2)

   b) BURNS & ROE DWG NO. 4156, REACTOR BLDG PRIMARY & SECONDARY SHIELDS PLAN AT EL. 376'-4" & 371'-10" (Rev 6)

3. BECHTEL CALCULATIONS:

   a) MISSILE SHIELD RIGGING · WIRE ROPE LENGTH TOLERANCE ANALYSIS CASE B, CALC. No. C-1-8, Rev 0

   b) MISSILE SHIELD RIGGING - SAFETY FACTORS VS ROPE TOLERANCE CASE A, CALC. NO. C-1-12, REV. 0

   c) COMPUTER PROGRAM DEVELOPED FOR MISSILE SHIELD RIGGING ANALYSIS - SAFETY FACTOR VS ROPE TOLERANCE, CASE A, CALC. No. C-1-13, REV 0

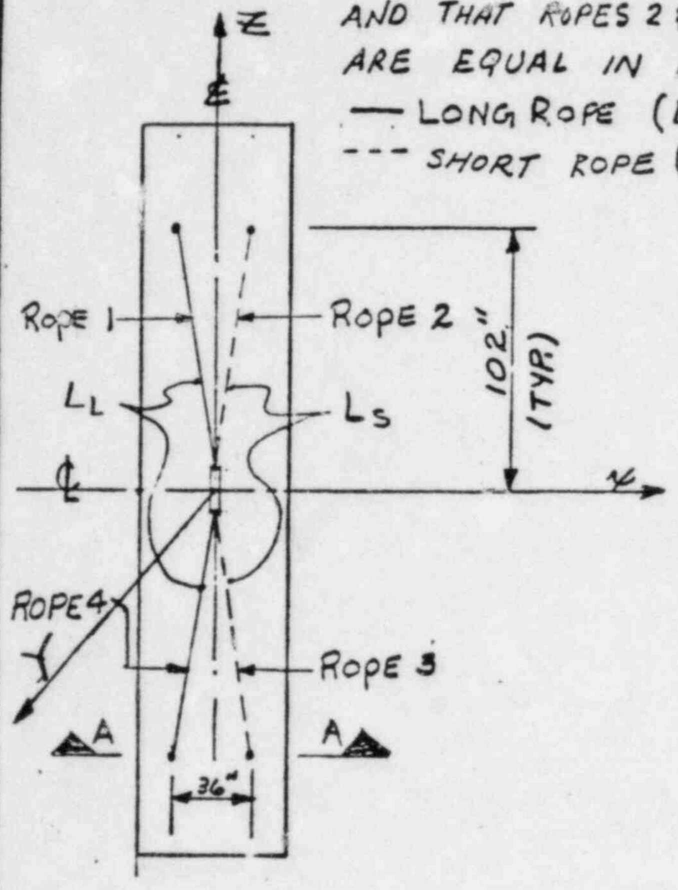
CALCULATION SHEET

BECHTEL	CALC. NO. C-1-9 REV. NO. 0
ORIGINATOR Francis M Forkey jr DATE 4-22-83	CHECKED C. IANNI DATE 4-29-83
PROJECT TMI-2	JOB NO. 15737
SUBJECT	SHEET NO. 3

CASE C : ASSUME ROPES 2 & 3 ARE SHORTER THAN ROPES 1 & 4, AND THAT ROPES 2 & 3 ARE EQUAL IN LENGTH. ALSO, ROPES 1 & 4 ARE EQUAL IN LENGTH.

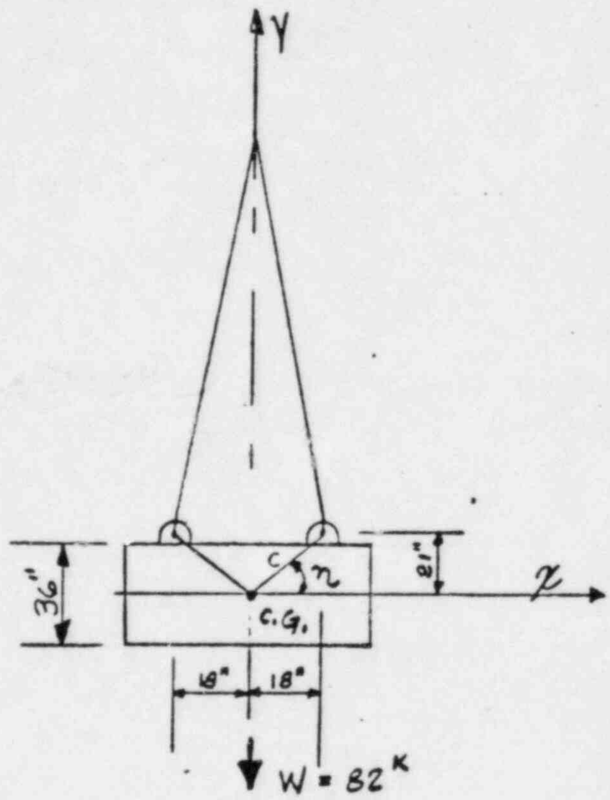
— LONG ROPE (L_L)

--- SHORT ROPE (L_S)



PLAN

(MISSLE SHIELD)



SECTION A-A

(INITIAL CONDITION)

FOR A F.S. OF 5 THE MAX LOAD/ROPE IS:

FROM REF. #2a.

Breaking strength = 66.1 TONS

MECH. EYE SPLICE AT ENDS OF ROPE HAVE A MIN. EFFICIENCY OF 92.5 %

$$\therefore T_{MAX} = \frac{.925(66.1)2}{5} = 24.46^K\ /\text{ROPE}$$

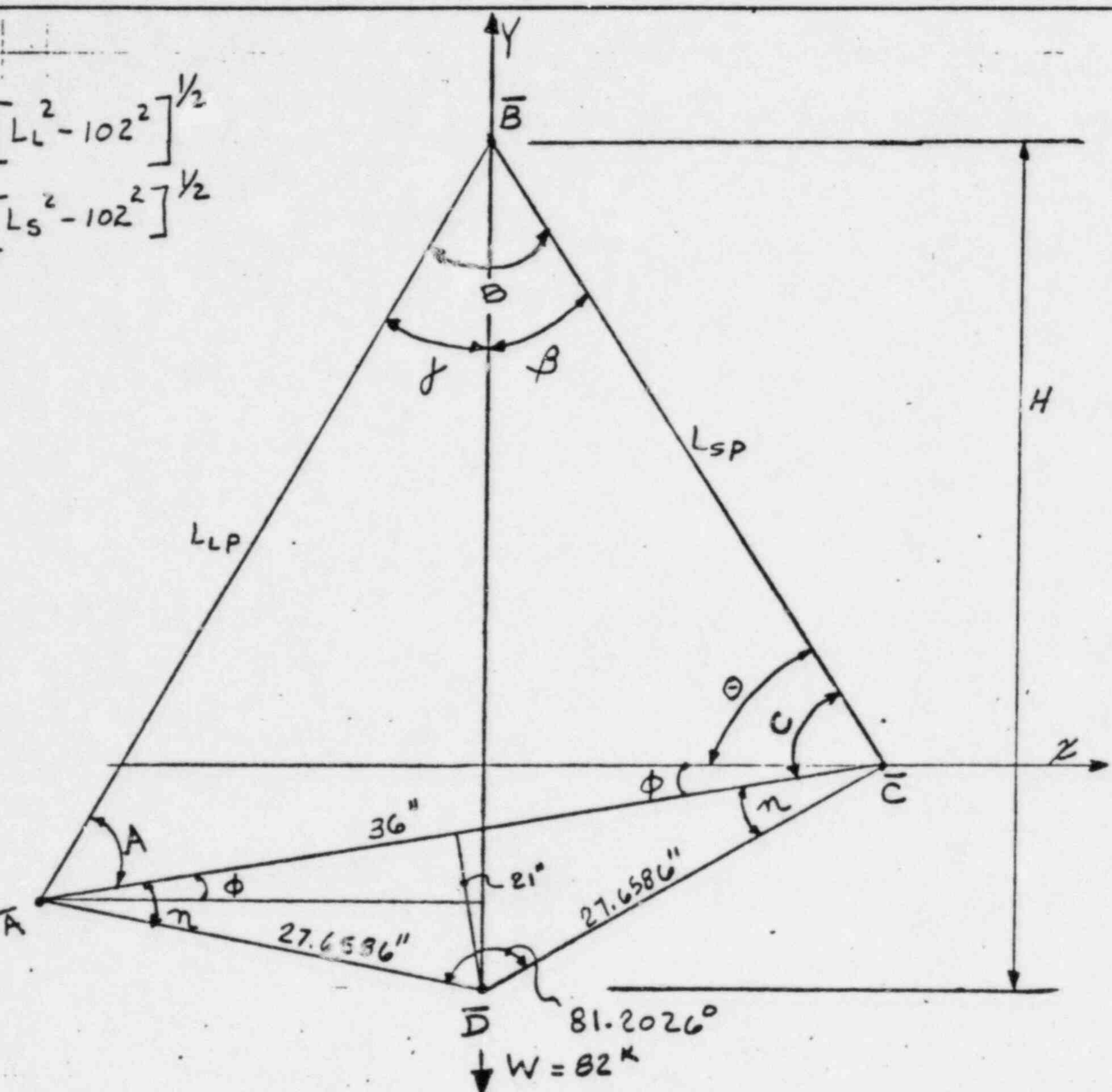
$$\tan \eta = \frac{21}{18} = 1.1667$$

$$\eta = 49.3987^\circ$$

$$C = \sqrt{18^2 + 21^2} = 27.6586"$$

$$L_{LP} = \left[L_L^2 - 102^2\right]^{1/2}$$

$$L_{LS} = \left[L_S^2 - 102^2\right]^{1/2}$$



FINAL CONDITION (SECTION A-A)

L_{SP}= LENGTH OF SHORT ROPES (PROJECTED INTO X-Y PLANE)

L_{LP}= LENGTH OF LONG ROPES (PROJECTED INTO X-Y PLANE)

F_{SR}= FORCE IN TWO SHORT ROPES (L_{SP})

F_{LP}= FORCE IN TWO LONG ROPES (L_{LP})

METHOD FOR SOLVING GEOMETRY AND FORCES ON ROPES

STEP 1 - CONSIDER TRIANGLE $\bar{A}, \bar{B}, \bar{C}$ SH. 4, BY THE LAW OF COSINES

$$\text{THE } \cos C = \frac{L_{SP}^2 + 36^2 - L_{LP}^2}{72\, L_{SP}}, \qquad \text{(EQ 1)}$$

$$\text{and THE } \cos B = \frac{L_{SP}^2 + L_{LP}^2 - 36^2}{2\, L_{SP} L_{LP}}, \qquad \text{(EQ 2)}$$

$$\text{and THE } \cos A = \frac{L_{LP}^2 + 36^2 - L_{SP}^2}{72\, L_{LP}} \qquad \text{(EQ 3)}$$

STEP 2 - CONSIDER TRIANGLE $\bar{B}, \bar{C}, \bar{D}$ SH. 4, BY THE LAW OF COSINES

$$H = \left[L_{SP}^2 + 27.6586^2 - 2(27.6586) L_{SP} \cos(C + \pi)\right]^{1/2} \qquad \text{(EQ 4)}$$

$$\text{and THE } \cos \beta = \frac{-27.6586^2 + L_{SP}^2 + H^2}{2\, L_{SP} H} \qquad \text{(EQ 5)}$$

$$\therefore \gamma = B - \beta \qquad \text{(EQ 6)}$$

STEP 3 - SUM FORCES IN THE VERT & HORZ DIRECTIONS

$$\Sigma F_H = 0 = -F_{LP} \sin \gamma + F_{SP} \sin \beta$$

$$\Sigma F_V = 0 = 82^k - F_{LP} \cos \gamma - F_{SP} \cos \beta$$

SOLVING TWO SIMULTANEOUS EQUATIONS FOR F_{LP} & F_{SP}

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-9 REV. NO. 0

ORIGINATOR Francis M Forkey Jr DATE 4-25-83 CHECKED C. IANNI DATE 4-29-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT SHEET NO. 6

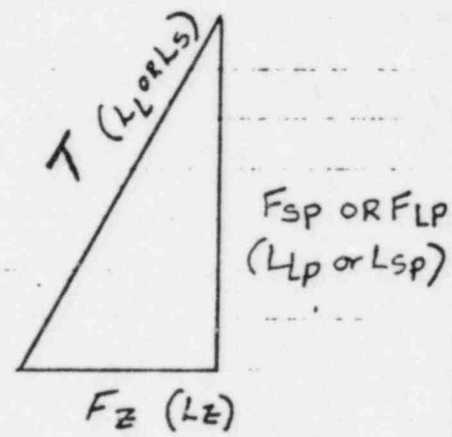
$$F_{LP} = \frac{82^{K}}{\left(\frac{\sin\gamma}{\sin\beta}\right)\cos\beta + \cos\gamma} \qquad \text{(EQ 7)}$$

$$F_{SP} = F_{LP}\left(\frac{\sin\gamma}{\sin\beta}\right) \qquad \text{(EQ 8)}$$

STEP 4 - FIND RESULTANT FORCES IN WIRE ROPES

$$F_Z = \frac{L_Z T}{L} \qquad L_Z = 102'' \qquad T = T_S \text{ OR } T_L \qquad L = L_S \text{ OR } L_L$$

$$T_S^2 = F_{SP}^2 + F_Z^2 \quad \text{AND} \quad T_L^2 = F_{LP}^2 + F_Z^2$$



FORCE TRIANGLE

WHERE T_S & T_L ARE THE TENSION LOADS IN THE TWO SHORT & TWO LONG WIRE ROPES RESPECTIVELY

BY SUBSTITUTION

$$T_S = \sqrt{\frac{F_{SP}^2}{1-\left(\frac{L_Z}{L_S}\right)^2}} \qquad \text{(EQ 9)}$$

$$T_L = \sqrt{\frac{F_{LP}^2}{1-\left(\frac{L_Z}{L_L}\right)^2}} \qquad \text{(EQ 10)}$$

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-9 REV. NO. 2

ORIGINATOR [signature] DATE 4-25-83 CHECKED C. IANNI DATE 4-29-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT SHEET NO. 7

EXAMPLE $\begin{cases} L_L = 205'' \rightarrow L_{LP} = \sqrt{205^2 - 102^2} = 177.82'' \\ L_S = 203'' \rightarrow L_{SP} = \sqrt{203^2 - 102^2} = 175.51'' \end{cases}$

STEP 1

EQ 1 $\cos C = \dfrac{175.51^2 + 36^2 - 177.82^2}{72(175.51)} = .037969$

$\angle C = 87.824°$

EQ 2 $\cos A = \dfrac{177.82^2 + 36^2 - 175.51^2}{72(177.82)} = .164976$

$\angle A = 80.504°$

EQ 3 $\cos B = \dfrac{175.51^2 + 177.82^2 - 36^2}{2(175.51)(177.82)} = .979322$

$\angle B = 11.672°$

STEP 2

EQ 4 $H = [175.51^2 + 27.6586^2 - 2(27.6586)(175.51)\cos(87.824 + 49.39)]^{1/2}$

$H = 196.71''$

EQ 5 $\cos \beta = \dfrac{27.6586^2 - 175.51^2 - 196.71^2}{-2(175.51)(196.71)} = .99543$

$\beta = \cos^{-1} .99543 = 5.47979°$

EQ6 $\therefore \gamma = B - \beta = 11.672 - 5.47979° = 6.1922°$

STEP 3

EQ 7 $F_{LP} = \dfrac{82}{\left(\dfrac{\sin 6.1922}{\sin 5.47979}\right)\cos 5.47979 + \cos 6.1922} = 38.71^K$

EQ 8 $F_{SP} = 38.71\left(\dfrac{\sin 6.1922}{\sin 5.47979}\right) = 43.72^K$

BECHTEL

CALCULATION SHEET

CALC. NO. C-1-9 REV. NO. 0

ORIGINATOR Francis M Forkey Jr. DATE 4-25-83 CHECKED C. IANNI DATE 4-29-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT SHEET NO. 8

STEP 4

EQ 8 $$T_S = \sqrt{\frac{43.72^2}{1-\left(\frac{102}{203}\right)^2}} = 50.57^K$$

EQ 9 $$T_L = \sqrt{\frac{38.71^2}{1-\left(\frac{102}{205}\right)^2}} = 44.62^K$$

FROM REF 2a - FOR 2 ROPES: $F_{allow} = 2(24.46^K) = 48.92^K$

WIRE ROPES SUPPLIED WERE EXTRA IMP. PLOW STEEL 1¼" ϕ, BREAKING STRENGTH = 79.9T

MECH EYE SPLICE Eff = 92.5% F_{allow} for 2 ropes = $\frac{.925(79.9)}{5}(2)(2) = 59.126^K$

T_L = LOAD ON 2 LONG ROPES
T_S = LOAD ON 2 SHORT ROPES

L_S (IN)	L_L (IN)	$\Delta = L_L - L_S$ (IN)	∡C (Deg)	∡B (Deg)	∡A (Deg)	C + η (Deg)	H (IN)	β (Deg)	γ (Deg)	T_L (KIPS)	T_S (KIPS)
203	203.25	1/4	84.5764	11.7627	83.6610	133.9751	195.73	5.8375	5.9252	47.30	48.03
↓	203.50	1/2	85.0394	11.7518	83.2088	134.4381	195.876	5.7866	5.9652	46.91	48.39
	203.75	3/4	85.5024	11.7403	82.7572	134.9011	196.02	5.7356	6.0047	46.52	48.75
	204.0	1	85.9660	11.7280	82.3060	135.3647	196.16	5.6854	6.0426	46.15	49.117
	204.25	1 1/4	86.4298	11.7150	81.8552	135.8285	196.30	5.6345	6.0805	45.77	49.48
	204.50	1 1/2	86.8939	11.7013	81.4048	136.2926	196.44	5.5828	6.1185	45.38	49.84
	204.75	1 3/4	87.3584	11.6868	80.9548	136.7571	196.58	5.5303	6.1565	44.99	50.21
	205.0	2	87.8231	11.6716	80.5052	137.2218	196.71	5.4810	6.1906	44.63	50.55
	210.0	7	97.2511	11.2183	71.5306	146.6498	199.20	4.3770	6.8413	36.80	58.06

CONCLUSION: A DIFFERENCE OF APPROXIMATELY 3/4 OF AN INCH BETWEEN TWO PAIRS OF WIRE ROPES WILL EXCEED A FACTOR OF SAFETY OF 5 FOR WIRE ROPES FROM REF 2. FOR THE ROPES SUPPLIED, A DIFFERENCE OF 7" DOES NOT EXCEED A S.F. OF 5.

CALCULATION COVER SHEET

BECHTEL

PROJECT T.M.I 2 JOB NO. 15737 CALC. NO. C-1-12

SUBJECT Missile Shield Rigging - Safety factors vs Rope Tolerance, CASE A

ORIGINATOR William L. Siskos DATE 4/29/83

CHECKER JCF DATE 4/30/83 NO OF SHEETS 14

RECORD OF ISSUES

NO.	DESCRIPTION	BY	DATE	CHKD	DATE	APPRD	DATE	ACCEPTANCE	DATE
0	Issued for Project Use	WS	4/29/83	JCF	[illegible]	[illegible]	[illegible]	[illegible]	5/4/[illegible]

- [ ] PRELIMINARY CALC.
- [ ] SUPERSEDED CALC.
- [ ] COMMITTED PRELIMINARY CALC.
- [x] FINAL CALC.

GPD-2704 Rev. 10/78 (ED-1)

BECHTEL

CALCULATION SHEET

CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L Siskos DATE 4/12/83 CHECKED GcF DATE 4/29/83

PROJECT T.M.I 2 JOB NO. 15737

SUBJECT Missile Shield Rigging - Wire Rope SHEET NO. 2

1. Purpose:

THE PURPOSE OF THIS CALCULATION IS TO EVALUATE THE SAFETY FACTOR OF THE ROPES USED IN A FOUR POINT LIFT OF A CONCRETE MISSILE SHIELD. IN THIS EVALUATION AS SHOWN ON PAGE #9 IT WAS ASSUMED THAT TWO DIAGONALLY LOCATED ROPES WERE OF EQUAL LENGTH WHILE THE OTHER DIAGONALLY LOCATED SET WAS ASSUMED LONGER. THE ASSUMPTION OF UNEQUAL ROPE LENGTH IS MADE IN ORDER TO ACCOUNT FOR TOLERANCE IN THE ROPES, SHACLES, AND LOCATION OF PICK UP POINTS. SINCE 80 TON MIN STRENGTH ROPES WERE FURNISHED INSTEAD OF THE 66.1 TON MIN STRENGTH ROPES CALLED FOR ON THE DRAWING, BOTH 66.1 TON AND 80 TON ROPES WERE EVALUATED. THE ROPES WERE FIRST ANALYZED WITHOUT TAKING INTO ACCOUNT THE EFFECT OF THEIR OWN ELONGATION AND THEN WERE ANALYZED INCLUDING THE EFFECT OF ELONGATION.

REFERENCE: DRAWING 2-COP-1302, REV. 2

CALCULATION SHEET

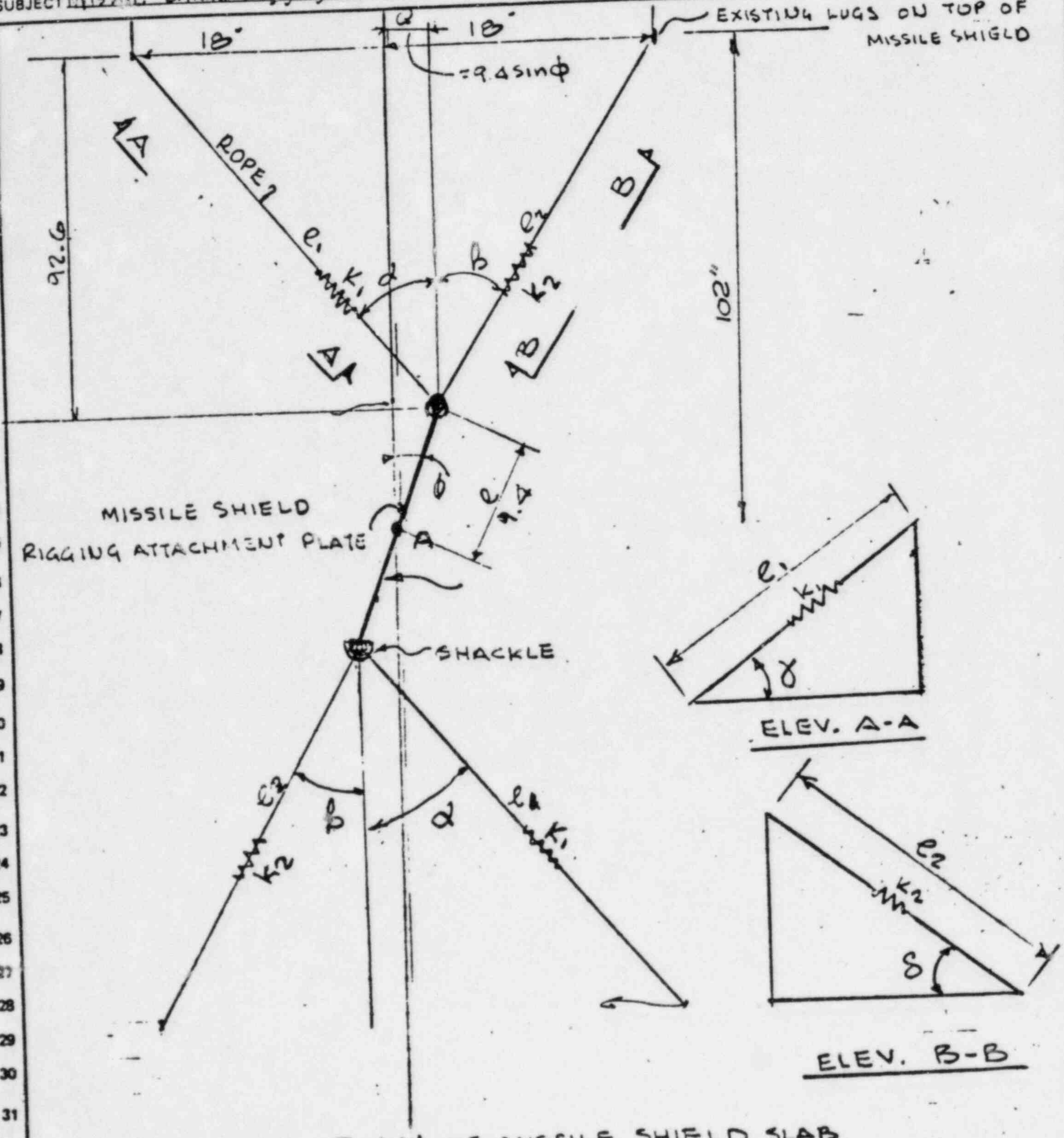
BECHTEL

CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L. Siskos DATE 4/17/83 CHECKED J.G.Fu DATE 4/27/83

PROJECT T.M.I. - 2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 3



PLAN OF MISSILE SHIELD SLAB

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L. Siskos DATE 4/19/83 CHECKED JeFr DATE 4/27/83

PROJECT T.M.I -2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.Frs Rope Tolerance SHEET NO. 4

EQUATIONS (W/O ELONGATION)

AT UPPER SHACLES

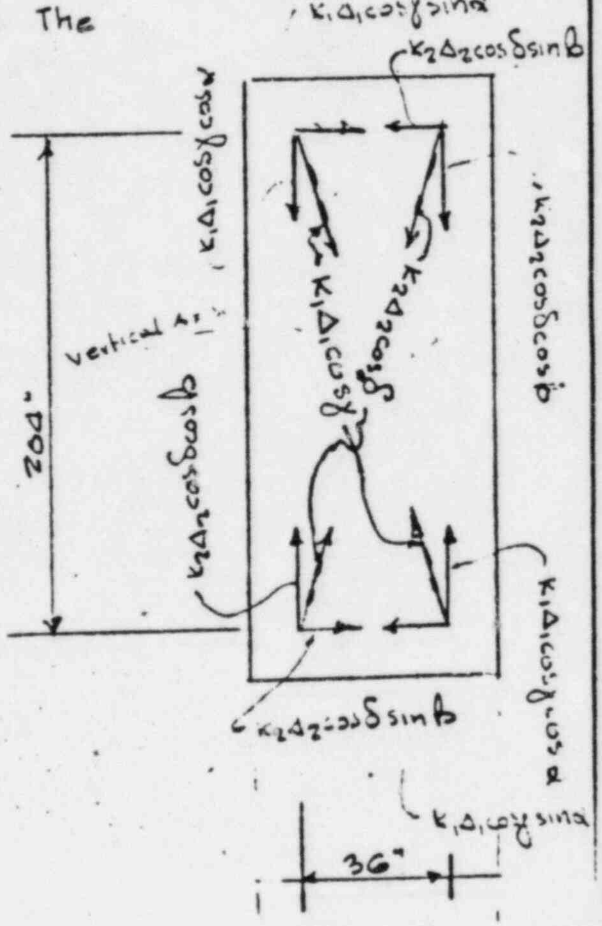
1) $\Sigma Y\uparrow^{+} = 82 - 2K_1\Delta_1 \sin\gamma - 2K_2\Delta_2 \sin\delta = 0$

2) $\Sigma \overset{\curvearrowright}{M_A} = -K_1\Delta_1\cos\gamma\sin\alpha(9.4\cos\phi) + K_2\Delta_2\cos\delta\sin\beta(9.4\cos\phi)$
$\quad - K_1\Delta_1\cos\gamma\cos\alpha(9.4\sin\phi) - K_2\Delta_2\cos\delta\cos\beta(9.4\sin\phi) = 0$

3) $l_1\sin\gamma = l_2\sin\delta$

About a vertical axis passing through center of Gravity and considering free body forces at Missile The following equation is also true.

4) $\Sigma \overset{\curvearrowright}{M_1} = 204K_1\Delta_1\cos\gamma\sin\alpha + 36K_2\Delta_2\cos\delta\cos\beta$
$\quad - 36K_1\Delta_1\cos\gamma\cos\alpha - 204K_2\Delta_2\cos\delta\sin\beta = 0$



WHERE

$K_1 = \dfrac{.72\times 12.6\times 10^3}{l_1}$

$K_2 = \dfrac{.72\times 12.6\times 10^3}{l_2}$

$\sin\alpha = \dfrac{18+9.4\sin\phi}{l_1\cos\gamma}$ $\quad \sin\beta = \dfrac{18-9.4\sin\phi}{l_2\cos\delta}$

$\cos\alpha = \dfrac{102-9.4\cos\phi}{l_1\cos\gamma}$ $\quad \cos\beta = \dfrac{102-9.4\cos\phi}{l_2\cos\delta}$

$\cos\gamma = \dfrac{\sqrt{(18-9.4\sin\phi)^2 + (102-9.4\cos\phi)^2}}{l_2}$

$\cos\delta = \dfrac{\sqrt{(18-9.4\sin\phi)^2 + (102-9.4\cos\phi)^2}}{l_2}$

$\sin\gamma = \dfrac{\sqrt{l_1^2 - (18+9.4\sin\phi)^2 - (102-9.4\cos\phi)^2}}{l_1}$

$\sin\delta = \dfrac{\sqrt{l_2^2 - (18-9.4\sin\phi)^2 - (102-9.4\cos\phi)^2}}{l_2}$

Given: l_1, l_2, K_1, K_2, solve for Δ_1, Δ_2, and Angle ϕ

For solution of above equations see pages 4 through 14 of Calculation C-1-13

CALCULATION SHEET

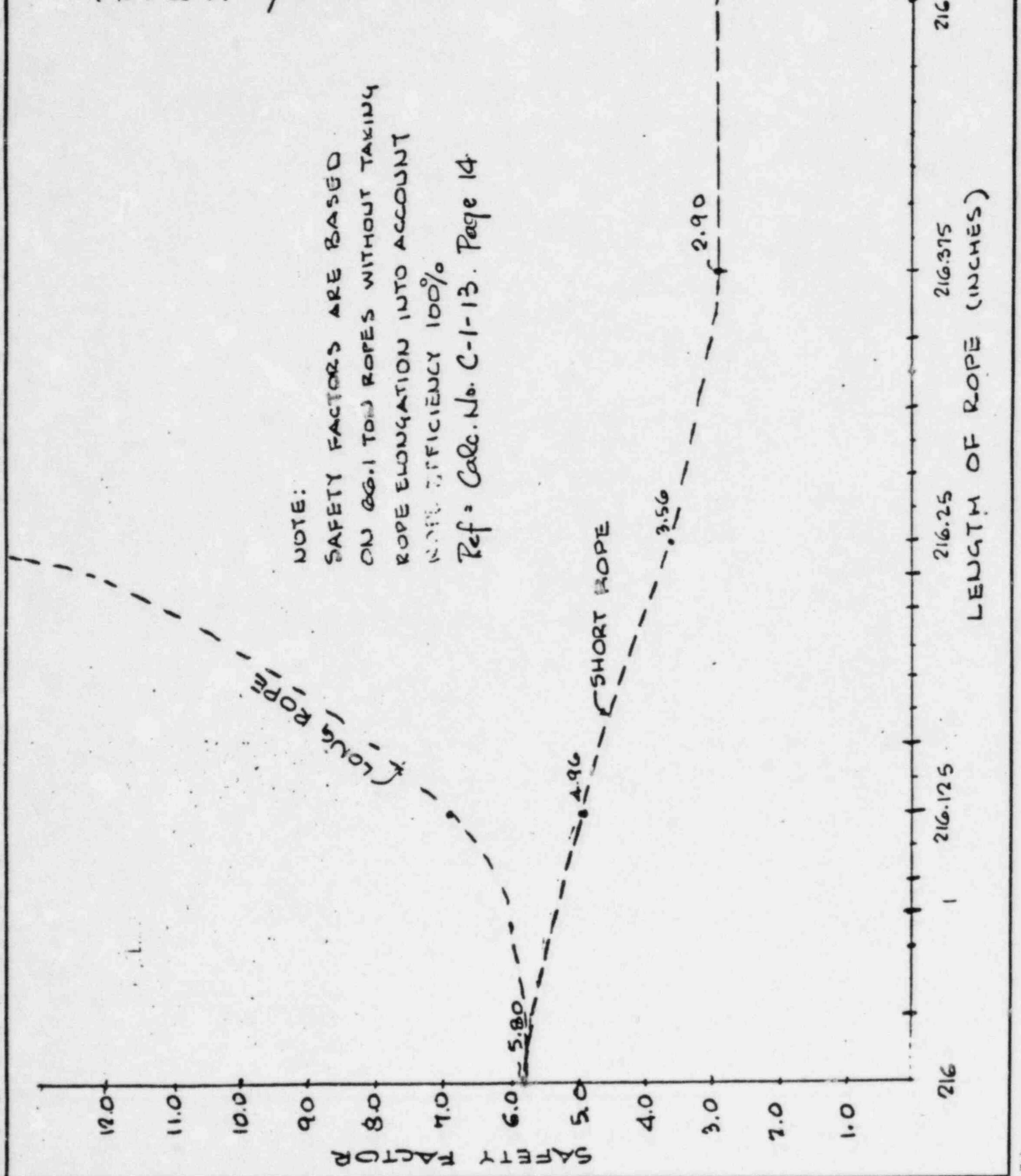
CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L. Sisko DATE 4/20/83 CHECKED JOH DATE 4/27/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 5

Tolerance Analysis (CASE A)



CALCULATION SHEET

BECHTEL

CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L. Siskos DATE 4/22/83 CHECKED [illegible] DATE 4/27/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F. vs Rope Tolerance SHEET NO. 6

Using Equations from Pg #4 and taking into account the elongation of Ropes:

1) $92 - 2K_1\Delta_1 \sin\gamma - 2K_2\Delta_2 \sin\delta = 0$

2) $204K_1\Delta_1\cos\gamma\sin\alpha + 36K_2\Delta_2\cos\delta\cos\beta - 36K_1\Delta_1\cos\gamma\cos\alpha$
$-204K_2\Delta_2\cos\delta\sin\beta = 0$

3) $(\ell_1+\Delta_1)\sin\gamma = (\ell_2+\Delta_2)\sin\delta$

WHERE:

$$K_1 = \frac{.72\times12.6\times10^3}{\ell_1+\Delta_1} = \frac{9072.0}{\ell_1+\Delta_1} \qquad K_2 = \frac{.72\times12.6\times10^3}{\ell_2+\Delta_2}$$

$$\sin\alpha = \frac{18+9.4\sin\phi}{(\ell_1+\Delta_1)\cos\gamma} \qquad \sin\beta = \frac{18-9.4\sin\phi}{(\ell_2+\Delta_2)\cos\delta}$$

$$\cos\alpha = \frac{102-9.4\cos\phi}{(\ell_1+\Delta_1)\cos\gamma} \qquad \cos\beta = \frac{102-9.4\cos\phi}{(\ell_2+\Delta_2)\cos\delta}$$

$$\cos\gamma = \frac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2}$$

$$\cos\delta = \frac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2}$$

$$\sin\gamma = \frac{\sqrt{(\ell_1+\Delta_1)^2-(18+9.4\sin\phi)^2-(102-9.4\cos\phi)^2}}{\ell_1+\Delta_1}$$

$$\sin\delta = \frac{\sqrt{(\ell_2+\Delta_2)^2-(18-9.4\sin\phi)^2-(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2}$$

Given sets of ℓ_1 & ℓ_2 find ϕ, Δ_1, Δ_2

GPD-2706 8/76 (ED-69)

BECHTEL

CALCULATION SHEET

CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William Sisko DATE 4/20/83 CHECKED J.J. DATE 4/27/83

PROJECT T.M.I.-2 JOB NO. 15737

SUBJECT Missile Shield Rigging S.F. vs Rope Tolerance SHEET NO. 7

$$\cos\gamma\sin\alpha = \frac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2} \times \frac{18+9.4\sin\phi}{(\ell_1+\Delta_1)\dfrac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2}}$$

$$\underline{\cos\gamma\sin\alpha} = \frac{18+9.4\sin\phi}{(\ell_1+\Delta_1)}$$

$$\cos\delta\sin\beta = \frac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2} \times \frac{(18-9.4\sin\phi)}{(\ell_2+\Delta_2)\dfrac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2}}$$

$$\underline{\cos\delta\sin\beta} = \frac{18-9.4\sin\phi}{(\ell_2+\Delta_2)}$$

$$\cos\delta\cos\beta = \frac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2} \times \frac{102-9.4\cos\phi}{(\ell_2+\Delta_2)\dfrac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{(\ell_2+\Delta_2)}}$$

$$\underline{\cos\delta\cos\beta} = \frac{102-9.4\cos\phi}{\ell_2+\Delta_2}$$

$$\cos\gamma\cos\alpha = \frac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2} \times \frac{102-9.4\cos\phi}{(\ell_1+\Delta_1)\dfrac{\sqrt{(18-9.4\sin\phi)^2+(102-9.4\cos\phi)^2}}{\ell_2+\Delta_2}}$$

$$\cos\gamma\cos\alpha = \frac{102-9.4\cos\phi}{(\ell_1+\Delta_1)}$$

1) $$82 - \frac{18{,}144\Delta_1\sqrt{(e_1+\Delta_1)^2-(18+9.4\sin\phi)^2-(102-9.4\cos\phi)^2}}{(e_1+\Delta_1)^2} - \frac{18144\Delta_2\sqrt{(e_2-\Delta_2)^2-(18-9.4\sin\phi)^2-(102-9.4\cos\phi)^2}}{(e_2+\Delta_2)^2} = 0$$

2) $$\frac{1{,}850{,}688}{(e_1+\Delta_1)^2}\Delta_1(18+9.4\sin\phi) + \frac{326{,}592\Delta_2\,(102-9.4\cos\phi)}{(e_2+\Delta_2)^2} - \frac{326{,}592\Delta_1(102-9.4\cos\phi)}{(e_1+\Delta_1)^2} - \frac{1{,}850{,}688\Delta_2(18-9.4\sin\phi)}{(e_2+\Delta_2)^2}$$

3) $$(e_1+\Delta_1)^2 - 676.8\sin\phi = (e_2+\Delta_2)^2$$

Given e_1, e_2 find: Δ_1, Δ_2, ϕ

For solution of above equations

See pages 15 through 28 of calculation C-1-13

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-12 REV. NO. 0

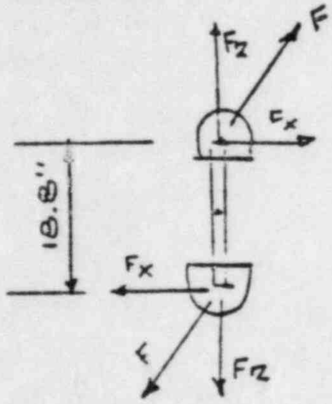
ORIGINATOR W. L. Siskins DATE 4-15-83 CHECKED JcFm DATE 4/27/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging-S.F vs Rope Tolerance SHEET NO. 9

CASE A

ASSUME ROPE #2 & ROPE #3
ARE SHORTER THAN ROPE #1
AND ROPE #4.
APPLY LOAD AT POINT A
VERTICALLY, ALONG Y AXIS.
AS SOON AS ROPES 2 & 3 ATTAIN
A SMALL AXIAL FORCE PLATE
A WILL ROTATE CLOCKWISE BECAUSE
OF UNBALANCED FORCES. SEE BELLOW



UNBALANCED MOMENT = $F_Z \times 18.8"$ ← ①

PLATE A WILL ROTATE CLOCKWISE
TILL CONDITION SHOWN IN FIG #2
IS ACHIEVED.

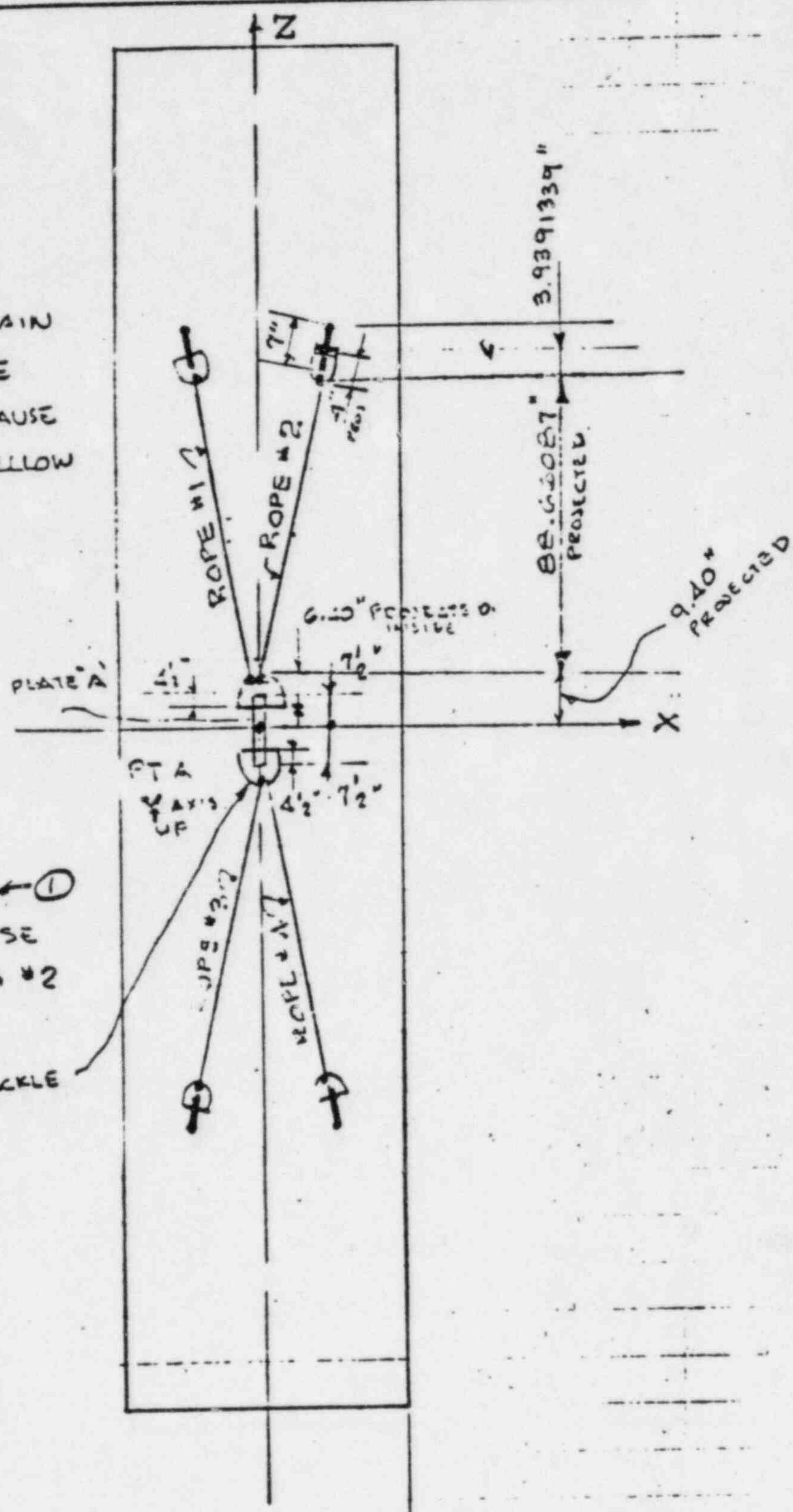


FIG #1

PLAN OF MISSILE SHIELD

CALCULATION SHEET

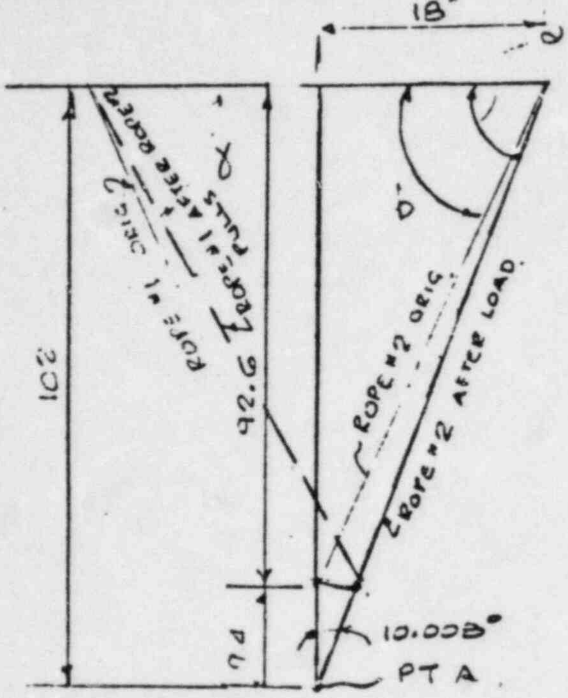
CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L. Siskos DATE 4-15-83 CHECKED JCF DATE 4/27/83

PROJECT T.M.I-2 JOB NO. 15737

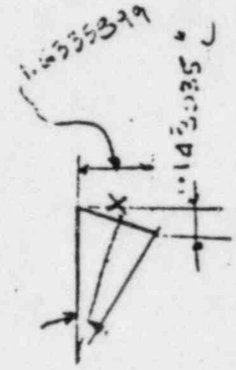
SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 10

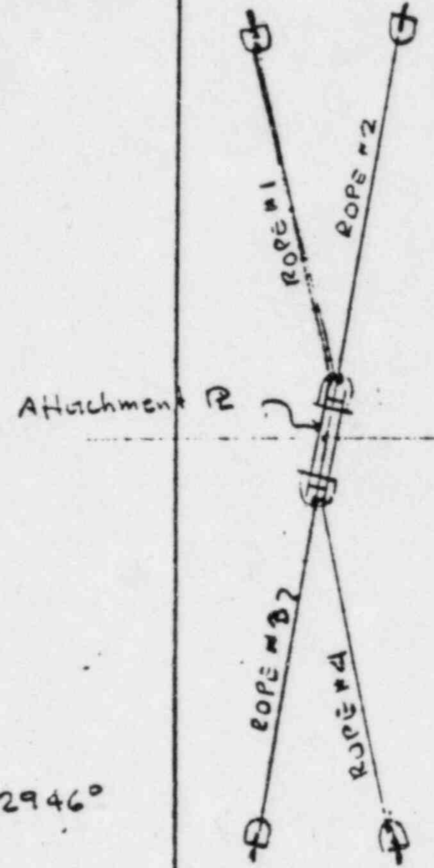
LENGTH OF ROPES WHEN ROPES 2 & 3 STARTING TO PICK UP FORCE



$\tan\beta = \frac{92.6}{18} = 5.14444$

$\beta = 78.99997842°$





$\sin\frac{10.008}{2} = .08722529 = \frac{x}{2\times 9.4}$

$x = 2\times 9.4\times .08722529 = 1.639E4"$

ORIGINAL PROJECTED LENGTH OF ROPE #1:

$= \frac{92.6}{\sin\beta} = \frac{92.6}{.9816264} = 94.3333"$ PROJECTED

$\tan\gamma = \frac{92.743035}{19.6335399} = 4.7236972176 \quad \gamma = 78.04702946°$

$\cos\gamma = .20710874 = \frac{19.6335399}{L}$

$L = 94.79846198$

$L_0 = 94.33333$

$\Delta L = .46516"$

When ropes 2 & 3 start picking up a force the attachment plate rotates clockwise till it gets the same direction as the horizontally projected direction of ropes 2 & 3. (See value of ΔL above). When Ropes 1 & 4 start picking up force the attachment plate starts rotating counterclockwise so that equilibrium of horizontal forces is always is obtained.

CALCULATION SHEET

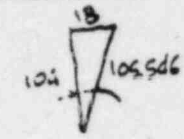
BECHTEL

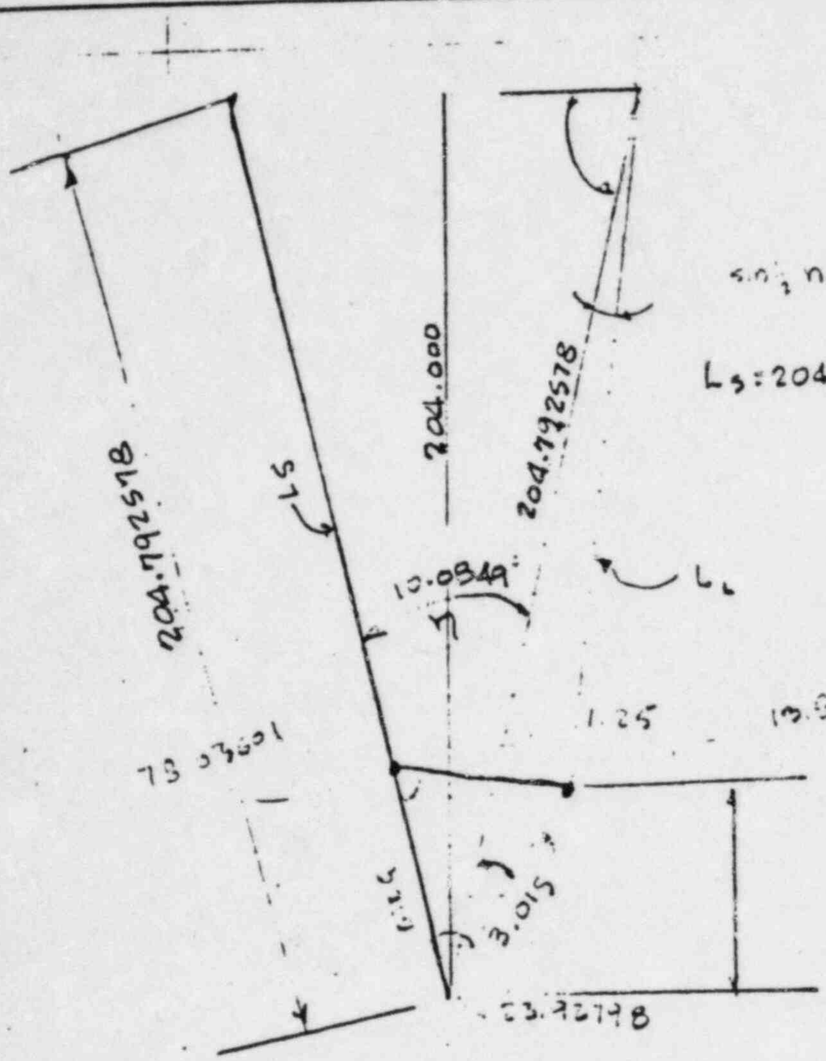
CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L. Siskos DATE 4-15-83 CHECKED JCFu DATE 4/29/83

PROJECT T.M.I-2 JOB NO. 15737

SUBJECT Missile Shield - S.F vs Rope Tolerance SHEET NO. 11

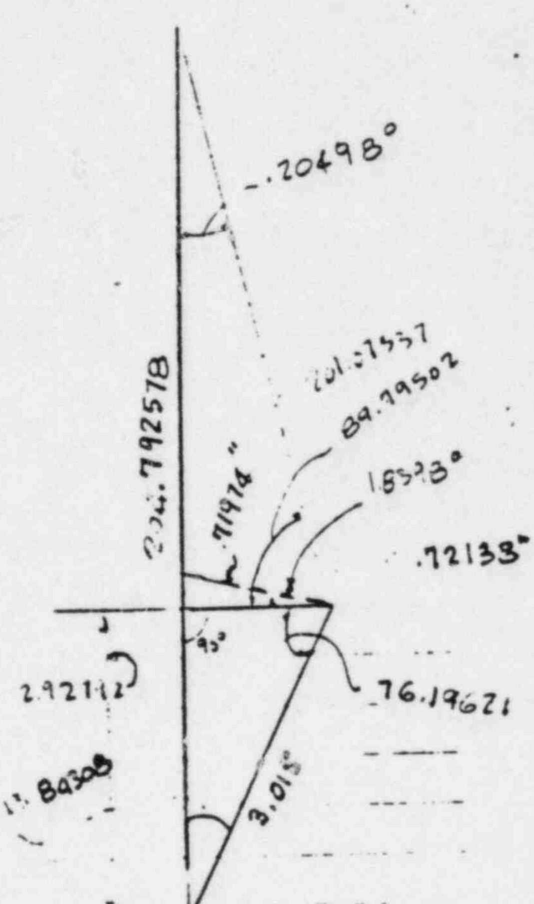




$\sin n = \frac{18}{204.792578} = .08789 \quad n = 10.0849°$

$L_S = 204.792578 - 3.015 = 201.777578"$

$23.92798 - 10.0849 = 13.84303°$



$\sin 13.84308 = \frac{x}{3.015}$

$x = .72138$

3.015 cos 13.84308 2.927423

$204.792578 - 2.927423 = 201.8652$

$L_L = \sqrt{201.8652^2 + .72138^2} = 201.8665$

$\Delta L = 201.8665 - 201.77578 = .090709"$

$L_L - L_S = .090709 \approx 3/32"$

CALCULATION SHEET

BECHTEL

CALC. NO. C-12 REV. NO. 0

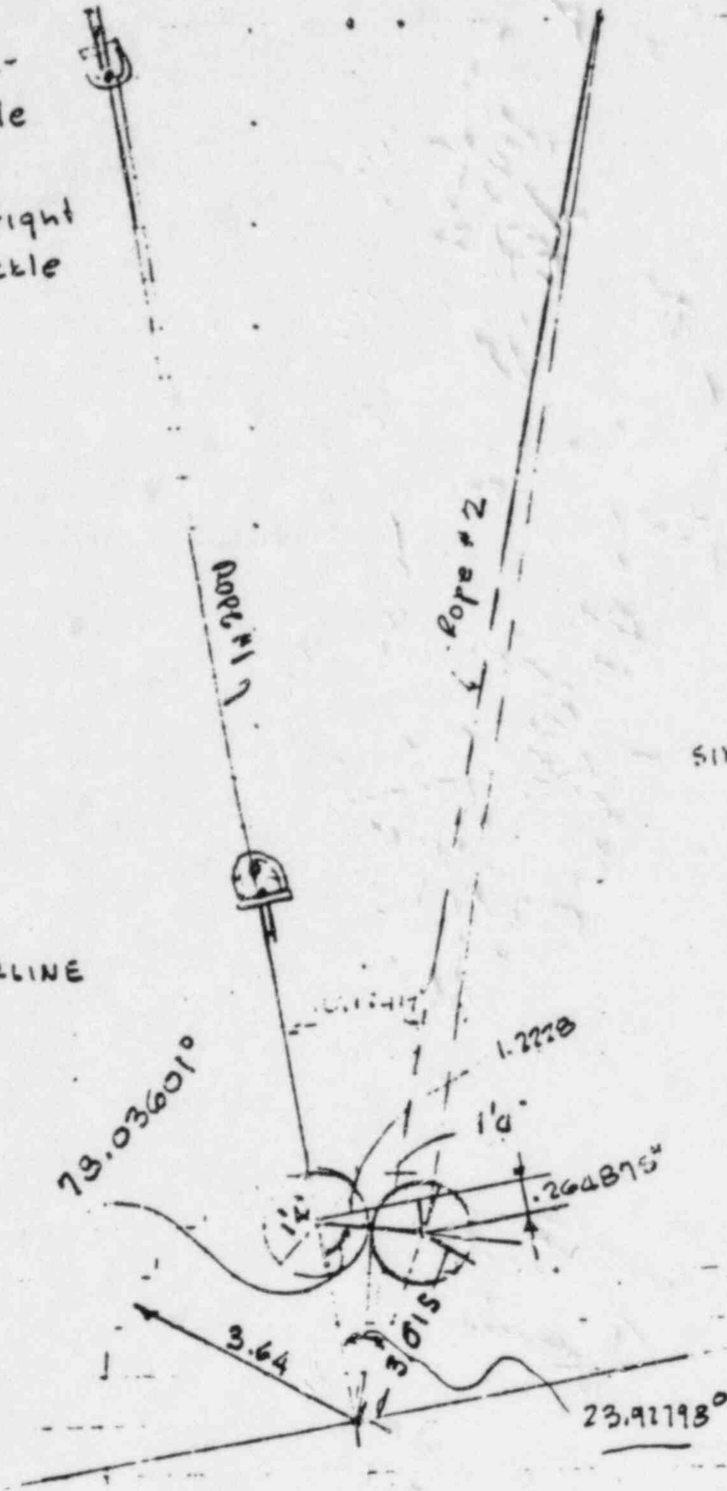
ORIGINATOR William L Sisson DATE 4-15-83 CHECKED JCL DATE 4/27/83

PROJECT T.M.I-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 12

SINCE ROPE 2 & 3 HAVE ORIGINALLY A FORCE, IT IS OBVIOUS THAT THE ROPE THAT TAKES THE FORCE WILL BE CENTERED AT THE SHACKLE.

In this case rope #1 (the short rope) will be centered at the shackle while rope #2 will be forced to move to the right and upwards in the shackle



$\tan \frac{23.92798}{2} = .2118917$

$\sin \frac{\alpha}{2} = \frac{.625}{3.015} = .20730$

$= 11.96399°$

$\alpha = 23.92798°$

ANGLE TO THE CENTERLINE OF PLATE =

$\frac{1}{2} \tan \phi'' = \frac{.625}{9.4}$

$\phi'' = 7.5746$

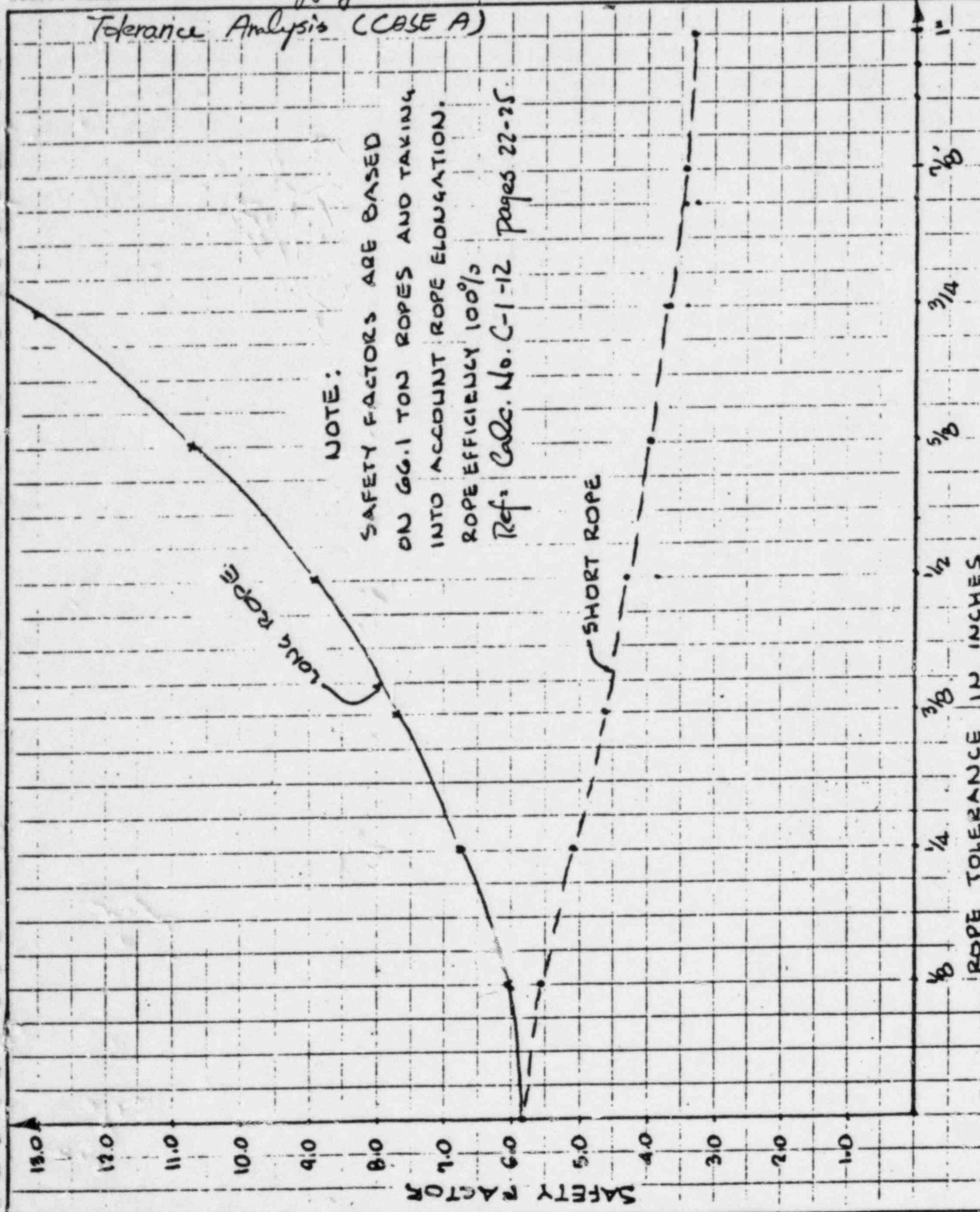
CALCULATION SHEET

CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L. Siskos DATE 4/25/83 CHECKED JCFu DATE 4/27/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 13



BECHTEL

CALCULATION SHEET

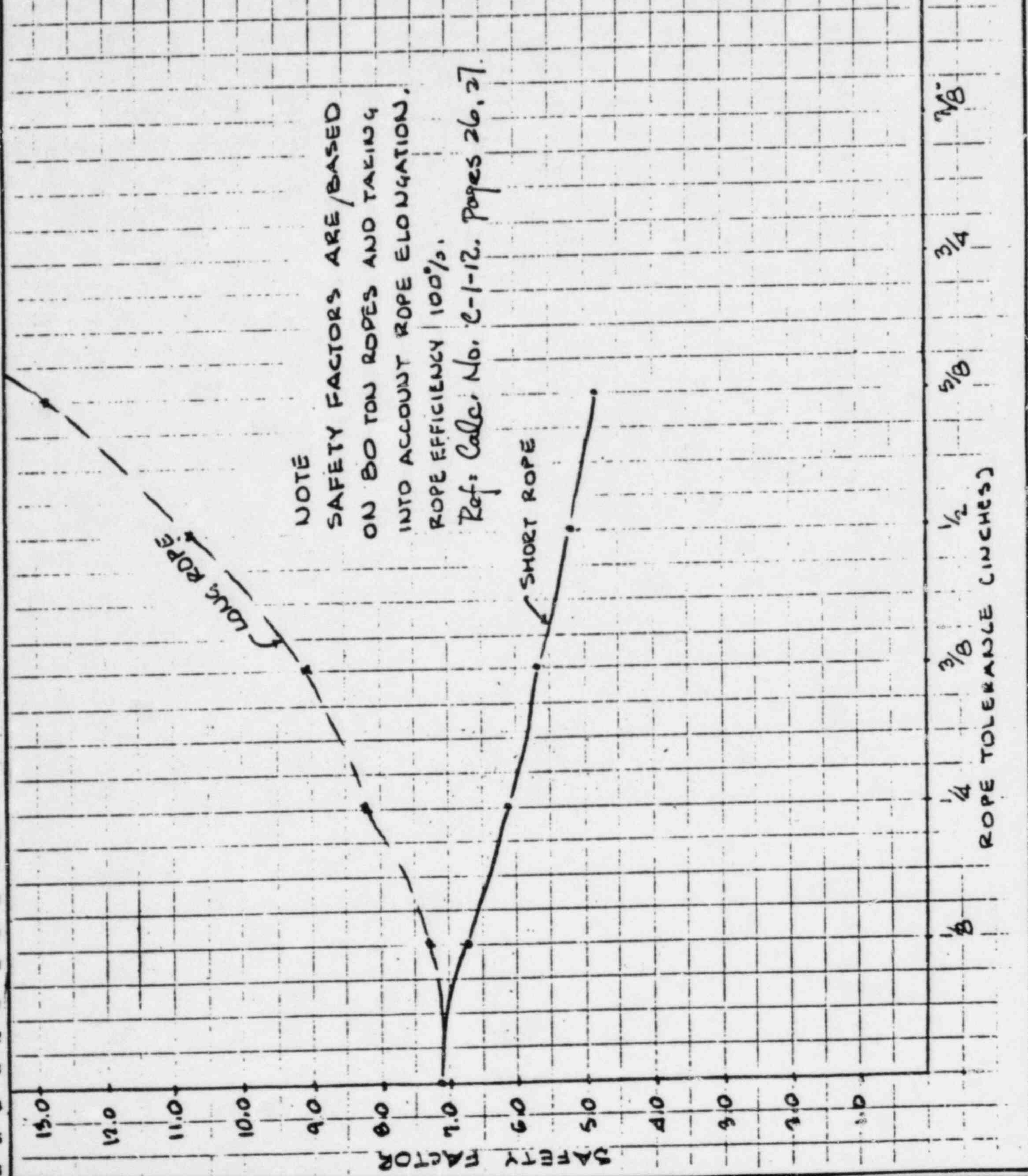
CALC. NO. C-1-12 REV. NO. 0

ORIGINATOR William L. Sisko? DATE 4/25/83 CHECKED JCFu DATE 4/27/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerances SHEET NO. 14

Tolerance Analysis (CASE A)



CALCULATION COVER SHEET

PROJECT TMI-2 JOB NO. 15737 CALC. NO. C-1-13

SUBJECT Computer Program Developed for Missile Shield Rigging Analysis - Safety Factors vs. Rope Tolerance, Case A

ORIGINATOR Jc Fu DATE 4/30/83

CHECKER W Sisnos DATE 4/30/83 NO OF SHEETS 28

RECORD OF ISSUES

NO.	DESCRIPTION	BY	DATE	CHKD	DATE	APPRD	DATE	ACCEPTANCE	DATE
0	Issued For Project Use	JcFu	4/30/83	WS	4/30/83	VL	5/5/83	[illegible]	5/5/83

☐ PRELIMINARY CALC.

☐ SUPERSEDED CALC.

☐ COMMITTED PRELIMINARY CALC.

☒ FINAL CALC.

GPU-2704 Rev. 10/78 (ED-1)

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/29/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs. Rope Tolerance Analysis (CASE A). SHEET NO. 2

TABLE OF CONTENTS

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/29/83 CHECKED WS DATE 4.29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F. vs. Rope SHEET NO. 3

Tolerance Analysis (Case A)

1 Purpose.

The purpose of this calculation is to generate a FORTRAN program to solve the three simultaneous equations generated in Calc. No. C-1-12. In calc No. C-1-12 gives all the equation derivations for the four point lift of a concrete missile shield. Two sets of solutions are evolved. First set is derived without the consideration of the rope elongation and the second set is with the consideration of the rope elongation plus the small angle variation. Accordingly, two versions of the program are generated to solve the equations established in Calc. No. C-1-12. Flowchart, program listing, verification and results are all included in this calculation.

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/29/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging S.F. vs Rope Tolerance Analysis (CASE A) SHEET NO. 4

2. Geometry, Equations and FORTRAN programs of Solution No. 1 (without considering the rope elogation).

In Calc. C-1-12 page 3 illustrated the geometric relationshipe of the missile shield rigging attachment plate, shackles, ropes and the lugs on top of missile shield. Assumptions are made that the attachment is infinite rigid, the ropes are always in tension (positive) as long as they are stiel taking loads. Elongations of the ropes are neglected in the equations to find the geometric relationship as shown in page 6.

Three simultaneous equations are established in Calc. C-1-1. Page 4. Eq. (1) and (2) (or (4)) are the equilibrium equations. Eq. (3) are the compatibility equation which demonstrates that the shackle is functioned as a joint. Since the complexity of the equations, a FORTRAN program running in CDC CYBERsystem are generated. Pages 5 and 6 show the flowchart of the program with ϕ angle as a incrementing number. Pages 7 and 8 are the listing of the program. Page 9 lists out the rope lengths l_1 and l_2 and the directions to run this program. Pages 10 and 11 are the output of the example runs with l_1 incrementing by 1/8" from 188.6666". Page 12 is the verification of the results obtained from the computer program. Page 13 tabulates the results of the lengths, elongations, forces and safety factors of two ropes for the example run. Since the field group reported that the actual length is 216", the numbers have been rerun based on the adjusted length and then shown in page 14.

BECHTEL

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED WS DATE 4/24/83

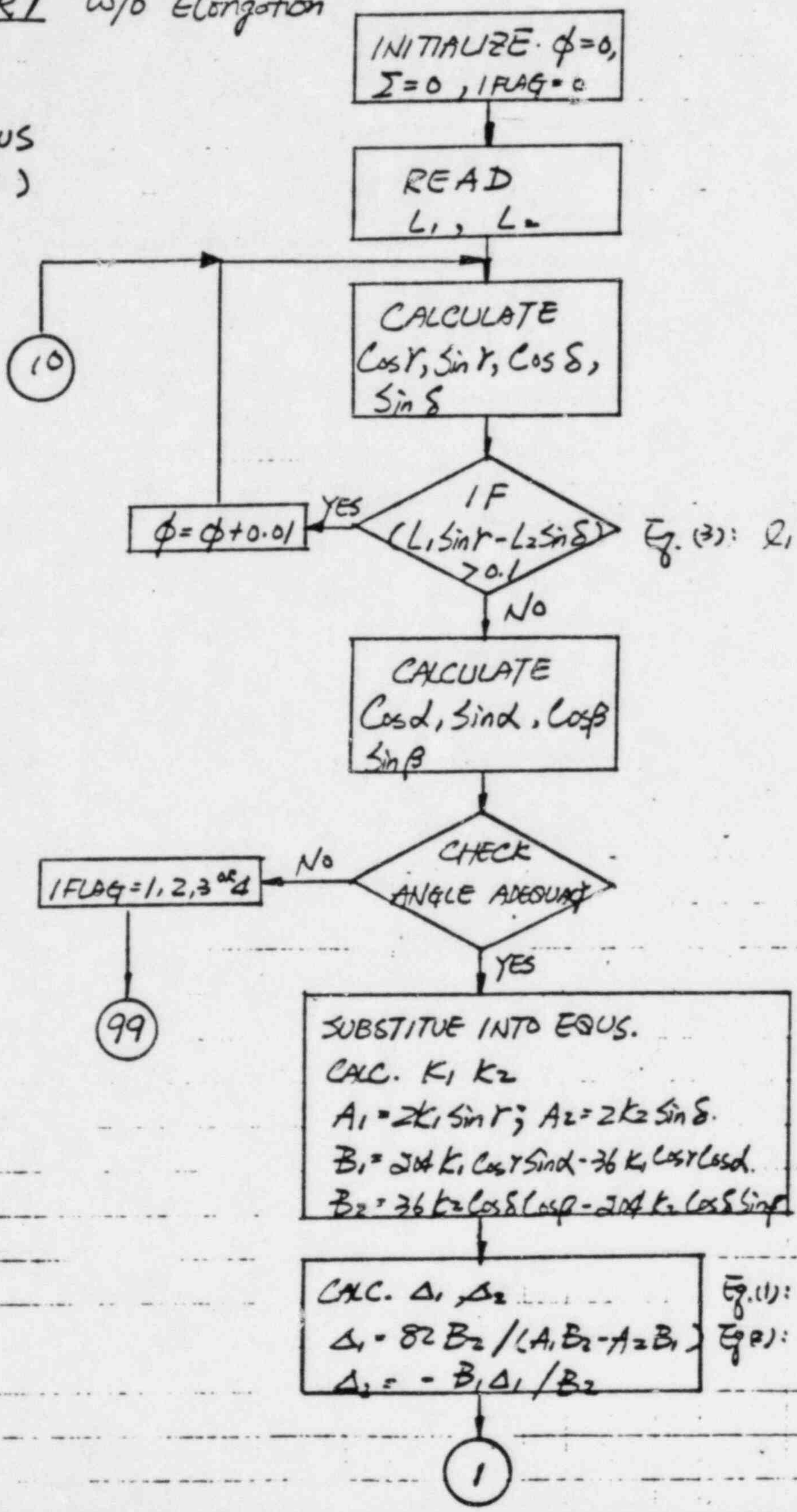
PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 5

Tolerance Analysis (CASE A)

FLOWCHART w/o Elongation

(SOLVING THREE SIMULTANEOUS EQUATION)



Eq.(3): $l_1 \sin\gamma = l_2 \sin\delta$

Eq.(1): $A_1\Delta_1 + A_2\Delta_2 = 82$

Eq.(2): $B_1\Delta_1 + B_2\Delta_2 = 0$

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CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

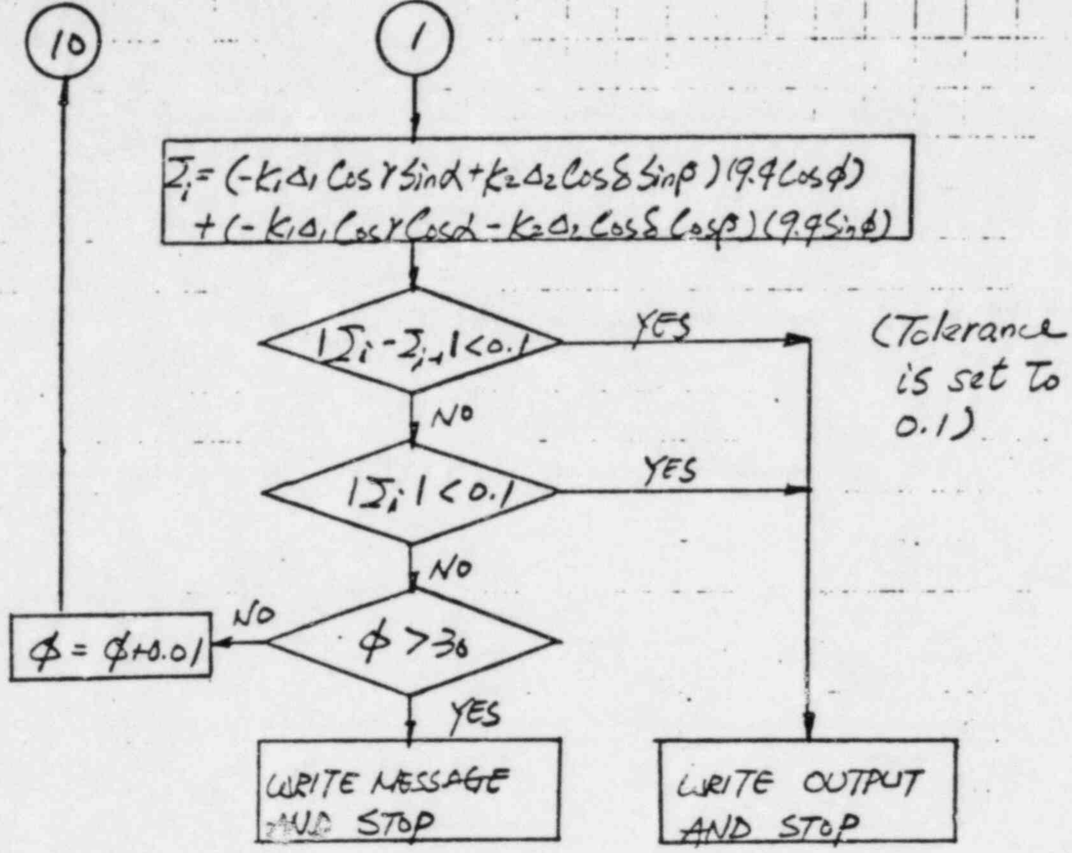
ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED WS DATE 4/24/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 6

Tolerance Analysis (CASE, A)

FLOWCHART (CONTINUED)



BECHTEL CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 7

Tolerance Analysis (CASE A)

PROGRAM LISTING (Rope Program Version 1)

```
[illegible] TAPE5=INPUT,TAPE6=OUTPUT)
      SIGMA=Ø.
      SIGM1=Ø.
      IFLAG=Ø.
      PHI=Ø.
      READ(5,*) X1,X2
      XX1=X1*X1
      XX2=X2*X2
   1Ø CPHI=9.4*COS(PHI)
      SPHI=9.4*SIN(PHI)
      CGAM=SQRT((18.+SPHI)**2+(1Ø2.-CPHI)**2)/X1
      CDET=SQRT((18.-SPHI)**2+(1Ø2.-CPHI)**2)/X2
      SGAM=SQRT(XX1-(18.+SPHI)**2-(1Ø2.-CPHI)**2)/X1
      SDET=SQRT(XX2-(18.-SPHI)**2-(1Ø2.-CPHI)**2)/X2
      IF(ABS(X1*SGAM-X2*SDET).GT.Ø.1) GO TO 4Ø
      SAFA=(18.+SPHI)/(X1*CGAM)
      CAFA=(1Ø2.-CPHI)/(X1*CGAM)
      CBET=(1Ø2.-CPHI)/(X2*CDET)
      SBET=(18.-SPHI)/(X2*CDET)
      IF(ABS(SAFA**2+CAFA**2-1).GT.Ø.ØØ1)IFLAG=1
      IF(ABS(SBET**2+CBET**2-1).GT.Ø.ØØ1)IFLAG=2
      IF(ABS(SGAM**2+CGAM**2-1).GT.Ø.ØØ1)IFLAG=3
      IF(ABS(SDET**2+CDET**2-1).GT.Ø.ØØ1)IFLAG=4
      IF(IFLAG.NE.Ø) GO TO 99
      XK1=.72*126ØØ./X1
      XK2=.72*126ØØ./X2
      A1=2.*XK1*SGAM
      A2=2.*XK2*SDET
      B1=2Ø4.*XK1*CGAM*SAFA-36.*XK1*CGAM*CAFA
      B2=36.*XK2*CDET*CBET-2Ø4.*XK2*CDET*SBET
C     B1=XK1*CGAM*CAFA
C     B2=XK2*CDET*CBET
C     B3=23.6725*COS(PHI)
C
```

(CONT'D)

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 8

Tolerance Analysis (CASE A)

PROGRAM LISTING (CONTD)

```
       DET1=82.*B2/(A1*B2-B1*A2)
       DET2=-(B1*DET1)/B2
C      DET1=(82.*B2-B3*A2)/(A1*B2-B1*A2)
C      DET2=(B3-B1*DET1)/B2
       SIGMA=(-XK1*DET1*CGAM*SAFA+XK2*DET2*CDET*SBET)*CPHI
     &      +(-XK1*DET1*CGAM*CAFA-XK2*DET2*CDET*CBET)*SPHI
       IF(ABS(SIGMA-SIGM1).LT.Ø.1) GO TO 5Ø
       IF(ABS(SIGMA).LT.Ø.1) GO TO 5Ø
       IF(PHI.GT.3Ø.) GO TO 9Ø
       SIGM1=SIGMA
   4Ø  PHI=PHI+Ø.Ø1
       GO TO 1Ø
   5Ø  WRITE(6,1ØØ) X1,X2,PHI,DET1,DET2,SIGMA,SIGM1
       GO TO 99
       STOP
   9Ø  WRITE(6,1Ø1)PHI,SIGMA
       STOP
   99  WRITE(6,1Ø2) IFLAG,PHI,SAFA,CAFA,SBET,CBET,SGAM,CGAM,SDET,CDET
       STOP
  1ØØ  FORMAT(1H ,"X1=",F1Ø.4,"X2=",F1Ø.4,/," PHI=",F1Ø.4,
     1 "DELTA1=",F1Ø.4,"DELTA2=",F1Ø.4,/,"SIGMA=",2F1Ø.4)
  1Ø1  FORMAT(1H ,"PHI ANGLE EXCEEDS ",F1Ø.4,"DEGREE",
     1 "SIGMA= ",F1Ø.4)
  1Ø2  FORMAT(1H ,"IFLAG=",I5,/,"PHI=",F1Ø.4,/,"SAFA,CAFA=",2F1Ø.4,/,
     $ "SBET,CBET=",2F1Ø.4
     1 ,/,"SGAM,CGAM=",2F1Ø.4,/,"SDET,CDET=",2F1Ø.4)
```

CALCULATION SHEET

BECHTEL

CALC. NO.	C-1-13	REV. NO.	0
ORIGINATOR	J C Fu	DATE	4/20/83
CHECKED	WS	DATE	4/29/83
PROJECT	TMI-2	JOB NO.	15737
SUBJECT	Missile Shield Rigging - S.F. vs. Rope Tolerance Analysis (CASE A)	SHEET NO.	9

(a) Procedures to run "Rope" program

(1) Dial CDC Rockville Center KA system.

(2) OLD, ROPE1 ← input command.

(3) BATCH:

(4) / FTN, I= ROPE1, L=0

(5) / LGO

(6) (Input l_1 and l_2 as free format).

(b) Example Run : Assume l_1 inital length as 188.6666" and increased 1/8" for each run and l_2 stays constant.

Run#	l_1	l_2
1	188.6666	188.6666
2	188.7916	"
3	188.9166	"
4	189.0416	"
5	189.1666	"
6	189.2916	"
7	189.4166	"
8	189.5416	"
9	189.6666	"

GPD-2706 8/76 (ED-69)

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F. vs Rope Tolerance SHEET NO. 10

Tolerance Analysis (CASE A) (Assume $l_1 = 188.6666 + \Delta$, $l_2 = 188.6666$)

OUTPUT (Rope Program Version 1) w/o Δ and ϕ in the Equation)

```
 X1=  188.6666X2=  188.6666
 PHI=     0.0000DELTA1=       .4923DELTA2=      .4923
SIGMA=     -.0000    0.0000
 IFLAG=     0
PHI=     0.0000
SAFA,CAFA=       .1908      .9816
SBET,CBET=       .1908      .9816
SGAM,CGAM=       .8660      .5000
SDET,CDET=       .8660      .5000
    STOP
```

(0°)

```
 X1=  188.7916X2=  188.6666
 PHI=      .0300DELTA1=      .4090DELTA2=      .5758
SIGMA=     -.0000    0.0000
 IFLAG=    0
PHI=      .0300
SAFA,CAFA=       .1937      .9811
SBET,CBET=       .1879      .9822
SGAM,CGAM=       .8660      .5000
SDET,CDET=       .8662      .4997
    STOP
```

(1.72°)

```
 X1=  188.9166X2=  188.6666
 PHI=      .1000DELTA1=      .2128DELTA2=      .7717
SIGMA=      .0000    0.0000
 IFLAG=    0
PHI=      .1000
SAFA,CAFA=       .2003      .9797
SBET,CBET=       .1811      .9835
SGAM,CGAM=       .8657      .5006
SDET,CDET=       .8664      .4993
    STOP
```

(5.73°)

```
 X1=  189.0416X2=  188.6666
 PHI=      .1700DELTA1=      .0135DELTA2=      .9706
SIGMA=      .0000    0.0000
 IFLAG=    0
PHI=      .1700
SAFA,CAFA=       .2067      .9784
SBET,CBET=       .1742      .9847
SGAM,CGAM=       .8652      .5014
SDET,CDET=       .8665      .4992
    STOP
```

(9.74°)

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 1587

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 1.1

Tolerance Analysis (CASE A)

```
  X1=  189.1666X2=  188.6666
  PHI=      .2400DELTA1=      -.1913DELTA2=     1.1745
 SIGMA=     .0000    0.0000
  IFLAG=     0
 PHI=      .2400                              (13.75°)
 SAFA,CAFA=       .2129       .9771
 SBET,CBET=       .1674       .9859
 SGAM,CGAM=       .8646       .5025
 SDET,CDET=       .8664       .4993
     STOP
  X1=  189.2916X2=  188.6666
  PHI=      .3100DELTA1=      -.4040DELTA2=     1.3859
 SIGMA=     .0000    0.0000
  IFLAG=     0
 PHI=      .3100                              (17.76°)
 SAFA,CAFA=       .2188       .9758
 SBET,CBET=       .1605       .9870
 SGAM,CGAM=       .8638       .5038
 SDET,CDET=       .8662       .4997
     STOP
  X1=  189.4166X2=  188.6666
  PHI=      .3800DELTA1=      -.6272DELTA2=     1.6074
 SIGMA=     .0000    0.0000
  IFLAG=     0
 PHI=      .3800                              (21.77°)
 SAFA,CAFA=       .2245       .9745
 SBET,CBET=       .1538       .9881
 SGAM,CGAM=       .8629       .5053
 SDET,CDET=       .8658       .5003
     STOP
  X1=  189.5416X2=  188.6666
  PHI=      .4600DELTA1=      -.8994DELTA2=     1.8771
 SIGMA=     .0000    0.0000
  IFLAG=     0
 PHI=      .4600                              (26.36°)
 SAFA [illegible]
 SBET,CBET=       .1462       .9893
 SGAM,CGAM=       .8617       .5074
 SDET,CDET=       .8652       .5014
     STOP
  X1=  189.6666X2=  188.6666
  PHI=      .5400DELTA1=     -1.1955DELTA2=     2.1700
 SIGMA=    -.0000    0.0000
  IFLAG=     0
 PHI=      .5400                              (30.94°)
 SAFA,CAFA=       .2362       .9717
 SBET,CBET=       .1388       .9903
 SGAM,CGAM=       .8604       .5097
 SDET,CDET=       .8644       .5028
     STOP
```

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED WS DATE 4/20/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F. vs. Rope SHEET NO. 12

Tolerance Analysis (CASE A)

VERIFICATION OF PROGRAM "ROPE" VERSION 1

1. $\ell_1 = 188.6666$, $\ell_2 = 188.6666$. (page 12)

Solution: $\Delta_1 = .4923$, $\Delta_2 = .4923$, $\phi = 0$.

$$\Sigma Y = 82 - 2K_1\Delta_1 \sin\gamma - 2K_2\Delta_2 \sin\delta = 82 - 2\frac{.72\times 12.6\times 10^3}{188.6666}(.4923)(.866)$$

$$- 2\frac{.72\times 12.6\times 10^3}{188.6666}(.4923)(.866) = 0$$ o.k.

$$\Sigma M = -K_1\Delta_1 \cos\gamma \sin\alpha (9.4\cos\phi) + K_2\Delta_2 \cos\delta \sin\beta (9.4\cos\phi)$$

$$- K_1\Delta_1 \cos\gamma \cos\alpha (9.4\sin\phi) - K_2\Delta_2 \cos\delta \cos\beta (9.4\sin\phi)$$

$$= \frac{.72\times 12.6\times 10^3}{188.6666}\times(.4923)(9.4)(-.5\times .908\times 1 + .5\times .908\times 1 + 0 + 0) = 0$$ o.k

$\ell_1 \sin\gamma = 188.6666\times .866 = \ell_2 \sin\delta$. o.k.

2. $\ell_1 = 189.0416$, $\ell_2 = 188.6666$ (page 12)

Solution: $\Delta_1 = 0.0135$, $\Delta_2 = .9706$, $\phi = 0.17$

$$\Sigma Y = 82 - 2\frac{.72\times 12.6\times 10^3}{189.0416}(0.0135)(.8652) - 2\frac{.72\times 12.6\times 10^3}{188.6666}(.9706)(.8665) = 0$$ o.k.

$$\Sigma M = \frac{.72\times 12.6\times 10^3}{189.0416}(0.0135)(9.4)(-.5014\times .2067\times \cos .17^r - .5014\times .9784\times \sin .17)$$

$$+ \frac{.72\times 12.6\times 10^3}{188.6666}(.9706)(9.4)(.4992\times .1742\cos .17^r - .4992\times .9847\sin .17)$$

$$= -0.01 \simeq 0$$ o.k.

$\ell_1 \sin\gamma = 189.0416\times .8652 = 163.56$

$\ell_2 \sin\delta = 188.6666\times .8665 = 163.480 \simeq 163.56$ o.k

(Tolerance of the program for the difference is set to 0.1)

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CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missle Shield Rigging - S.F vs. Rope Tolerance SHEET NO. 13

Tolerance Analysis (CASE A)

RESULTS FOR THE EXAMPLE RUN, $\ell_1 = 188.6666 + \Delta$"; $\ell_2 = 188.6666$"

1	2	3	4	5	6	7	8*	9
Length of Ropes 2 & 3 (INC)	Length of Ropes 1 & 4 (INC)	Δ_1 or Δ_4	Δ_2 or Δ_3	F_1 or F_4	F_2 or F_3	S.F. FOR ROPES 2 & 3	S.F FOR ROPES 1 & 4	Angle ϕ 1 AV. S.F.
188.6666	188.6666	.4923	.4923	23.672^k	23.672^k	5.59	5.59	0°
"	188.7916	.4090	.5758	19.654	27.637	6.72	4.8	1.72°
"	188.9166	.2128	.7717	10.219	37.107	12.93	3.6	5.73°
"	189.0416	.0135	.9706	0.648	46.671	204.0	2.83	9.74°
"	189.1666	0	.9846	—	47.344	INF	2.80	10.08°

* The safety factors given on column #8 are in the conservative side since do not include the effect of the location of the ropes in the upper shackle, as shown on pages 9 thru 12 of Calc. No. C-1-12.

K = 48.08 k/in for balanced condition

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/20/83 CHECKED [illegible] DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - SF vs Rope Tolerance SHEET NO. 14

Analysis (CASE A)

OUTPUT FOR THE PRODUCTION RUN.

$l_1 = 216.0 + 0$

$l_2 = 216.0$

Capacity = 66.1 T

```
X1=  216.0000X2=  216.0000
PHI=      0.0000DELTA1=       .5426DELTA2=      .5426
SIGMA=     -.0000    0.0000
IFLAG=    0
PHI=    0.0000
SAFA.CAFA=       .1908      .9816
SBET.CBET=       .1908      .9816
SGAM.CGAM=       .8996      .4367
SDET.CDET=       .8996      .4367
STOP
```

$K_1 = \frac{.72 \times 12{,}600}{216} = 42.0$ k/in

$P_{1\,(S.L)} = 42 \times .54 \times 6 = 22.79$

```
X1=  216.1250X2=  216.0000
PHI=      .0300DELTA1=       .4507DELTA2=      .6346
SIGMA=      .0000    0.0000
IFLAG=    0
PHI=      .0300
SAFA.CAFA=       .1937      .9811
SBET.CBET=       .1879      .9822
SGAM.CGAM=       .8996      .4367
SDET.CDET=       .8997      .4365
STOP
```

$K_2 = 41.97510305$

$P_{(S)} = 26.63$

```
/ GU.DRILL
X1=  216.2500X2=  216.0000
PHI=      .1100DELTA1=       .2034DELTA2=      .8818
SIGMA=     -.0000    0.0000
IFLAG=    0
PHI=      .1100
SAFA.CAFA=       .2012      .9795
SBET.CBET=       .1801      .9836
SGAM.CGAM=       .8993      .4374
SDET.CDET=       .8999      .4361
```

$K_3 = 41.95144591$

$P_{(S)} = 36.99$

```
X1=  216.3750X2=  216.0000
PHI=      .1900DELTA1=      -.0489DELTA2=     1.1335
SIGMA=     -.0000    0.0000
IFLAG=    0
PHI=      .1900
SAFA.CAFA=       .2085      .9780
SBET.CBET=       .1723      .9850
SGAM.CGAM=       .8988      .4384
SDET.CDET=       .8999      .4360
STOP
```

CALCULATION SHEET

BECHTEL

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PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 15

Analysis (CASE A).

3. Geometry, Equations and FORTRAN program of Solution No. 2 (with considering the rope elongation and small angle variation)

As the rope elongations being taken into account, the three simultaneous equations and the geometric equations in Calc. C-1-12 page 4 are changed to the forms shown in Calc. C-1-12 Pages 6, 7 and 8. In the same calculation are also shown the detail of the geometry. Small angle variation ϕ'' between two ropes can be found when the shorter rope lines up with the rigid plate. The finding of this angle ϕ are shown in Page 16 based on the geometry shown in Calc. C-1-12 pages 9 thru 12.
Since ϕ'' is a variable, the formulation of the angles ϕ_1 and ϕ_2 for ropes 1 and 2 is shown in Page 16 and the geometric equations for α, β, γ and δ are shown in Page 17. Pages 18 and 19 show the flowchart of the algorithm considering the rope elongation and small angle variation. Since Δ_1, Δ_2 and ϕ are all unknowns which can not be solved simultaneously by the program, Δ_1 and Δ_2 are the first incremental loop inside the program and ϕ angle is the final incremental loop until all the conditions are satisfied.

Pages 20 and 21 give the program listing. Pages 22 through 25 give the results for the ropes with capacity of 132.2^K (66.1^T). Page 26 and 27 show the results for capacity of 160^K (80^T). Verification by hand is shown in Page 28.

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

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PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Riggin - S.F vs Rope Tolerance SHEET NO. 16

Tolerance Analysis (CASE A)

(1). Find the Angle ϕ_F when Rope 2 takes all the load

then $K_1\Delta_1 = 0$

$\therefore \; K_2\Delta_2 \cos\delta\,(36\cos\beta - 204\sin\beta) = 0$

From the geometry

$$\sin\beta = \frac{18 - 9.4\sin\phi_F}{(l_2+\Delta_2)\cos\delta} \quad \text{where } \phi'' = 0$$

$$\cos\beta = \frac{102 - 9.4\cos\phi_F}{(l_2+\Delta_2)\cos\delta}$$

$$\therefore 36\,(102 - 9.4\cos\phi_F) - 204\,(18 - 9.4\sin\phi_F) = 0$$

$$\therefore \phi_F = \tan^{-1}\frac{36}{204} = 10.008^\circ \quad (0.1747\ \text{Rad})$$

(2). When ϕ is between 0 and ϕ_F. ϕ is a variable

Boundary Condition of ϕ:

When $\phi = 0$ $\quad \phi_1 = -\frac{\phi''}{2}$, $\phi_2 = \frac{\phi''}{2}$

$\phi \geq \phi_F$ $\quad \phi_1 = \phi - \phi''$. $\phi_2 = \phi$

where $\phi'' = 7.5746^\circ$ (or 0.1322 rad.)

So when $0 < \phi < \phi_F$

$$\phi_1 = -\frac{\phi''}{2} + \phi\left(\frac{\phi_F - \frac{\phi''}{2}}{\phi_F}\right)$$

$$\phi_2 = \frac{\phi''}{2} + \phi\left(\frac{\phi_F - \frac{\phi''}{2}}{\phi_F}\right)$$

(3). The geometry equations for α, β, γ, δ with ϕ_1 and ϕ_2 angles are as follows:

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/27/83 CHECKED WS DATE 4/24/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging-S.F. & Rope Tolerance SHEET NO. 17

Tolerance Analysis (CASE A)

$$\cos\gamma = \frac{\sqrt{(18+9.4\sin\phi_1)^2+(102-9.4\cos\phi_1)^2}}{(l_1+\Delta_1)}$$

$$\sin\gamma = \frac{\sqrt{(l_1+\Delta_1)^2-(18+9.4\sin\phi_1)^2-(102-9.4\cos\phi_1)^2}}{(l_1+\Delta_1)}$$

$$\cos\delta = \frac{\sqrt{(18-9.4\sin\phi_2)^2+(102-9.4\cos\phi_2)^2}}{(l_2+\Delta_2)}$$

$$\sin\delta = \frac{\sqrt{(l_2+\Delta_2)^2-(18-9.4\sin\phi_2)^2-(102-9.4\cos\phi_2)^2}}{(l_2+\Delta_2)}$$

$$\sin\alpha = \frac{18+9.4\sin\phi_1}{(l_1+\Delta_1)\cos\gamma}$$

$$\cos\alpha = \frac{102-9.4\cos\phi_1}{(l_1+\Delta_1)\cos\gamma}$$

$$\sin\beta = \frac{18-9.4\sin\phi_2}{(l_2+\Delta_2)\cos\delta}$$

$$\cos\beta = \frac{102-9.4\cos\phi_2}{(l_2+\Delta_2)\cos\delta}$$

CALCULATION SHEET

BECHTEL

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PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance Analysis (CASE A) SHEET NO. 18

FLOWCHART (SOLVING THREE SIMULTANEOUS EQUATIONS FOR THREE UNKNOWNS Δ_1, Δ_2, ϕ)

Rope Program (Version 2)

INITIALIZE $\phi = 0$, $\Sigma = 0$, IFLAG = 0.
$\phi_F = \tan^{-1}(36/204)$
$\phi' = 0.1322^{rad}$.

↓

READ X_1, X_2

↓

$X_{t1} = X_1 + \Delta_1$; $X_{t2} = X_2 + \Delta_2$
and calc. X_{t1}^2, X_{t2}^2 ← (5)

↓

$\phi < \phi_F$:

$\phi_1 = -\frac{\phi'}{2} + \phi\left(\frac{\phi_F - \frac{\phi'}{2}}{\phi_F}\right)$

$\phi_2 = \frac{\phi'}{2} + \phi\left(\frac{\phi_F - \frac{\phi'}{2}}{\phi_F}\right)$

$\phi \geq \phi_F$:

$\phi_1 = \phi - \phi'$

$\phi_2 = \phi$

↓

CALCULATE $\cos\alpha, \sin\alpha$, $\cos\gamma, \sin\gamma, \cos\delta, \sin\delta$, $\cos\beta, \sin\beta$

↓

SUBSTITUTE INTO EQUS.
CALCULATE K_1, K_2.
$A_1 = 2K_1 \sin\gamma$; $A_2 = 2K_2 \sin\delta$
$B_1 = 204 K_1 \cos\gamma \sin\alpha - 36 K_1 \cos\gamma \cos\alpha$
$B_2 = 36 K_2 \cos\delta \cos\beta - 204 K_2 \cos\delta \sin\beta$

↓

CALCULATE Δ_1, Δ_2
$\Delta_1 = 82 B_2 / (A_1 B_2 - A_2 B_1)$
$\Delta_2 = -B_1 \Delta_1 / B_2$

$A_1\Delta_1 + A_2\Delta_2 = 82$ (1)
$B_1\Delta_1 + B_2\Delta_2 = 0$ (2)

↓

(1)

CALCULATION SHEET

BECHTEL

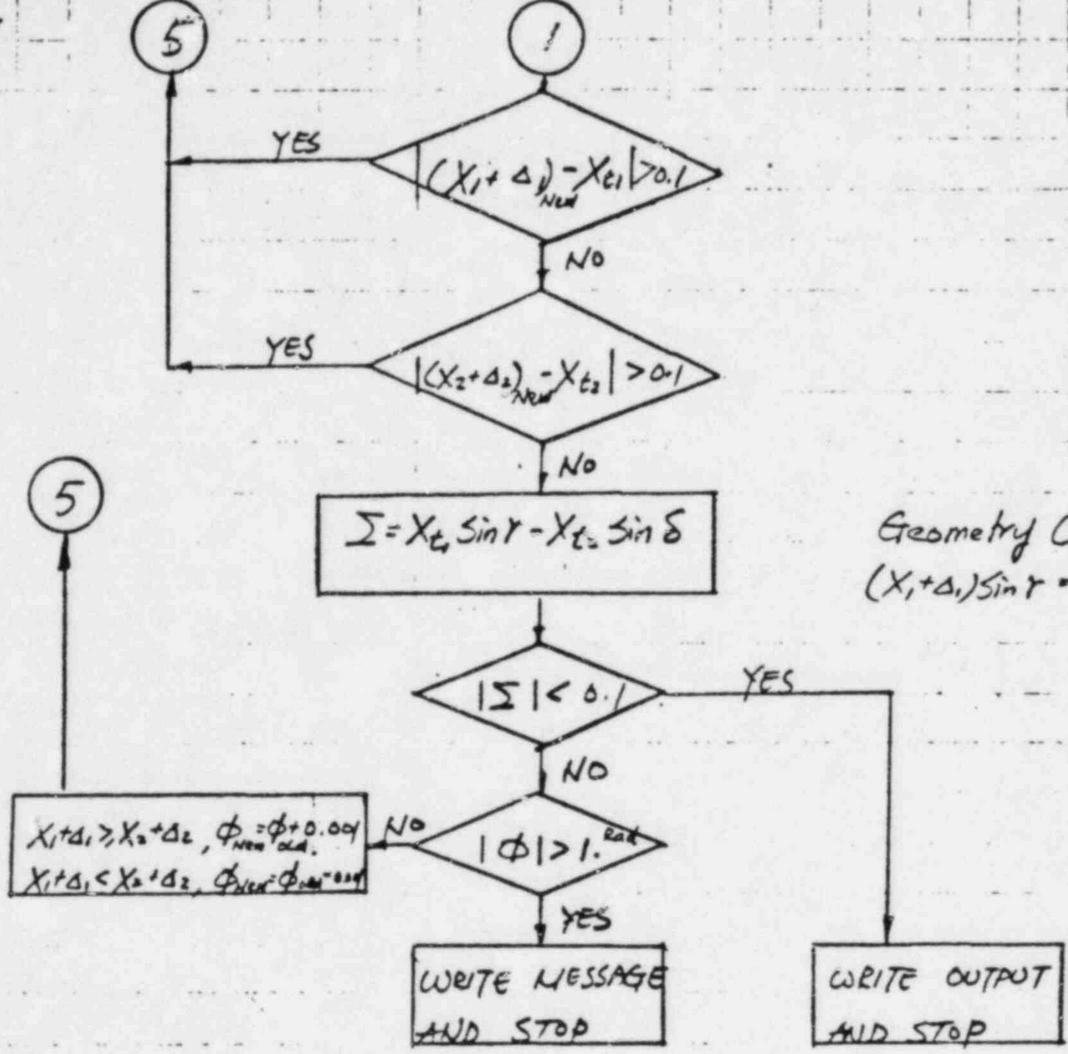
CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/27/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance Analysis (CASE A) SHEET NO. 19

FLOWCHART (CONT'D).



Geometry Compatibility

$(X_1+\Delta_1)\sin\gamma = (X_2+\Delta_2)\sin\delta$ (*)

GPD-2706 8/76 (ED-69)

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/27/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance Analysis (CASE A) SHEET NO. 20

PROGRAM LISTING (Rope Program Version 2)

```
      PROGRAM DYN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
       SIGMA=0.
       SIGM1=0.
       IFLAG=0.
       KONT=0
       PHI=0.
       PHIF=ATAN(36./204.)
       PHII=0.1322
       DET1=0.
       DET2=0.
       WRITE(6,110)
       READ(5,*) X1,X2
    5  XT1=X1+DET1
       XT2=X2+DET2
       XXT1=XT1*XT1
       XXT2=XT2*XT2
       PHI1=-PHII/2.+PHI*((PHIF-PHII/2.)/PHIF)
      IF(PHI.GE.PHIF) PHI1=PHI-PHII
       PHI2= PHII/2.+PHI*((PHIF-PHII/2.)/PHIF)
      IF(PHI.GE.PHIF) PHI2=PHI
       CPHI1=9.4*COS(PHI1)
       SPHI1=9.4*SIN(PHI1)
       CPHI2=9.4*COS(PHI2)
       SPHI2=9.4*SIN(PHI2)
       CGAM=SQRT((18.+SPHI1)**2+(102.-CPHI1)**2)/XT1
       CDET=SQRT((18.-SPHI2)**2+(102.-CPHI2)**2)/XT2
       SGAM=SQRT(XXT1-(18.+SPHI1)**2-(102.-CPHI1)**2)/XT1
       SDET=SQRT(XXT2-(18.-SPHI2)**2-(102.-CPHI2)**2)/XT2
C     IF(ABS(XT1*SGAM-XT2*SDET).GT.0.1) GO TO 40
       SAFA=(18.+SPHI1)/(XT1*CGAM)
       CAFA=(102.-CPHI1)/(XT1*CGAM)
       CBET=(102.-CPHI2)/(XT2*CDET)
       SBET=(18.-SPHI2)/(XT2*CDET)
C     IF(ABS(SAFA**2+CAFA**2-1).GT.0.001)IFLAG=1
C     IF(ABS(SBET**2+CBET**2-1).GT.0.001)IFLAG=2
C     IF(ABS(SGAM**2+CGAM**2-1).GT.0.001)IFLAG=3
C     IF(ABS(SDET**2+CDET**2-1).GT.0.001)IFLAG=4
      IF(IFLAG.NE.0) GO TO 99
       XK1=.72*12600./XT1
       XK2=.72*12600./XT2
       A1=2.*XK1*SGAM
       A2=2.*XK2*SDET
       B1=204.*XK1*CGAM*SAFA-36.*XK1*CGAM*CAFA
       B2=36.*XK2*CDET*CBET-204.*XK2*CDET*SBET
```

(CONT'D)

GPD-2706 8/76 (ED-69)

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/27/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 21

Analysis (CASE A)

(CONTD)

```
C
       DET1=82.*B2/(A1*B2-B1*A2)
       DET2=-(B1*DET1)/B2
C     DET1=(82.*B2-B3*A2)/(A1*B2-B1*A2)
C     DET2=(B3-B1*DET1)/B2
C     SIGMA=(-XK1*DET1*CGAM*SAFA+XK2*DET2*CDET*SBET)*CPHI
C    &      +(-XK1*DET1*CGAM*CAFA-XK2*DET2*CDET*CBET)*SPHI
C     WRITE(6,100) X1,X2,PHI,DET1,DET2,SIGMA,SIGM1,PHI1,PHI2
      KONT=KONT+1
      IF(KONT.GT.500) GO TO 99
      IF(ABS(X1+DET1-XT1).GT.0.1) GO TO 5
      IF(ABS(X2+DET2-XT2).GT.0.1) GO TO 5
      SIGMA=XT1*SGAM-XT2*SDET
C     IF(ABS(SIGMA-SIGM1).LT.0.1) GO TO 50
      IF(ABS(SIGMA).LT.0.1) GO TO 50
      SIGM1=SIGMA
   40 IF(ABS(PHI).GT.1.) GO TO 90
      IF((X1+DET1).GE.(X2+DET2))PHI=PHI+0.001
      IF((X1+DET1).LT.(X2+DET2))PHI=PHI-0.001
      GO TO 5
   50 WRITE(6,100) X1,X2,PHI,DET1,DET2,SIGMA,SIGM1,PHI1,PHI2
      P1=XK1*DET1
      P2=XK2*DET2
      SF1=160.0/P1
      SF2=160.0/P2
      WRITE(6,103)P1,P2,SF1,SF2
      GO TO 99
   90 WRITE(6,101)PHI,SIGMA
   99 WRITE(6,102) IFLAG,PHI,SAFA,CAFA,SBET,CBET,SGAM,CGAM,SDET,CDET
      STOP
  100 FORMAT(1H ,"X1=",F10.4," X2=",F10.4,/," PHI=",F10.4,
     1 " DELTA1=",F10.4," DELTA2=",F10.4,/," SIGMA=",2F10.4,
     2 " PHI1=",F10.4," PHI2=",F10.4)
  101 FORMAT(1H ,"PHI ANGLE EXCEEDS ",F10.4,"DEGREE",
     1 "SIGMA= ",F10.4)
  102 FORMAT(1H ,"IFLAG=",I5,/,"PHI=",F10.4,/,"SAFA,CAFA=",2F10.4,/,
     $ "SBET,CBET=",2F10.4
     1 ,/,"SGAM,CGAM=",2F10.4,/,"SDET,CDET=",2F10.4)
  103 FORMAT(1H ,//,"P1=",F10.4,"P2=",F10.4,/
     1 "S.F. 1=",F10.4,"S.F. 2=",F10.4,//)
  110 FORMAT(1H ,"INPUT X1 AND X2 ==>")
      END
```

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/25/83 CHECKED WT DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance Analysis (CASE A) SHEET NO. 22

CAPACITY = 132.2 K

OUTPUT OF THE PRODUCTION RUN

```
X1=  216.0000 X2=  216.0000
PHI=     0.0000 DELTA1=      .5435 DELTA2=      .5435
SIGMA=     0.0000     0.0000 PHI1=     -.0661 PHI2=      .0661

P1=   22.7692P2=   22.7692
S.F. 1=     5.8061S.F. 2=     5.8061

 IFLAG=     0
PHI=     0.0000
SAFA,CAFA=       .1844      .9828
SBET,CBET=       .1844      .9828
SGAM,CGAM=       .9003      .4352
SDET,CDET=       .9003      .4352
     STOP

X1=  216.1250 X2=  216.0000
PHI=      .0070 DELTA1=      .5221 DELTA2=      .5651
SIGMA=      .0933      .1009 PHI1=     -.0617 PHI2=      .0705

P1=   21.8635P2=   23.6719
S.F. 1=     6.0466S.F. 2=     5.5847

 IFLAG=     0
PHI=      .0070
SAFA,CAFA=       .1848      .9828
SBET,CBET=       .1840      .9829
SGAM,CGAM=       .9004      .4350
SDET,CDET=       .9004      .4351
     STOP

X1=  216.2500 X2=  216.0000
PHI=      .0250 DELTA1=      .4664 DELTA2=      .6210
SIGMA=      .0961      .1037 PHI1=     -.0506 PHI2=      .0816

P1=   19.5256P2=   26.0068
S.F. 1=     6.7706S.F. 2=     5.0833

 IFLAG=     0
PHI=      .0250
SAFA,CAFA=       .1859      .9826
SBET,CBET=       .1829      .9831
SGAM,CGAM=       .9005      .4349
SDET,CDET=       .9004      .4350
     STOP
```

BECHTEL

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J C Fu DATE 4/25/83 CHECKED WJ DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 23

Tolerance Analysis (CASE A) CAPACITY = 132.2K (CONTD)

```
X1=  216.3750 X2=  216.0000                  .6769
PHI=      .0430 DELTA1=      .4107 DELTA2=
SIGMA=      .0988      .1064 PHI1=      -.0394 PHI2=      .0928

P1=   17.1870P2=   28.3424
S.F. 1=    7.6919S.F. 2=    4.6644

 IFLAG=    0
PHI=      .0430
SAFA,CAFA=      .1870      .9824
SBET,CBET=      .1818      .9833
SGAM,CGAM=      .9005      .4348
SDET,CDET=      .9005      .4348
     STOP

X1=  216.5000 X2=  216.0000                  .7360
PHI=      .0620 DELTA1=      .3518 DELTA2=
SIGMA=      .0938      .1014 PHI1=      -.0276 PHI2=      .1046

P1=   14.7167P2=   30.8095
S.F. 1=    8.9830S.F. 2=    4.2909

[illegible]
SAFA,CAFA=      .1682      .9821
SBET,CBET=      .1807      .9835
SGAM,CGAM=      .9005      .4348
SDET,CDET=      .9006      .4346
     STOP

X1=  216.6250 X2=  216.0000                  .7921
PHI=      .0800 DELTA1=      .2959 DELTA2=
SIGMA=      .0962      .1038 PHI1=      -.0164 PHI2=      .1158

P1=   12.3748P2=   33.1483
S.F. 1=   10.6830S.F. 2=    3.9881

 IFLAG=    0
PHI=      .0200
SAFA,CAFA=      .1892      .9819
SBET,CBET=      .1796      .9837
SGAM,CGAM=      .9006      .4347
SDET,CDET=      .9007      .4345
     STOP
```

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR G.C. Fu DATE 4/25/83 CHECKED WJ DATE 4/29/83

PROJECT TMI-II JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 24

Tolerance Analysis (CASE A) CAPACITY = 132.2^k (CONT'D)

```
 X1=  216.7500 X2=   216.0000
 PHI=       .0980 DELTA1=        .2399 DELTA2=       .8483
 SIGMA=      .0984       .1061 PHI1=      -.0052 PHI2=       .1270

P1=   10.0302P2=    35.4896
S.F. 1=   13.1802S.F. 2=     3.7250

 IFLAG=     0
PHI=       .0980
SAFA,CAFA=       .1903      .9817
SBET,CBET=       .1785      .9839
SGAM,CGAM=       .9006      .4347
SDET,CDET=       .9007      .4344
    STOP

 X1=  216.8750 X2=   216.0000
 PHI=       .1170 DELTA1=        .1807 DELTA2=       .9077
 SIGMA=      .0928       .1004 PHI1=       .0066 PHI2=       .1388

P1=    7.5518P2=    37.9646
S.F. 1=   17.5059S.F. 2=     3.4822

 IFLAG=     0
PHI=       .1170
SAFA,CAFA=       .1914      .9815
SBET,CBET=       .1773      .9842
SGAM,CGAM=       .9006      .4347
SDET,CDET=       .9008      .4342
    STOP

 X1=  217.0000 X2=   216.0000
 PHI=       .1350 DELTA1=        .1245 DELTA2=       .9641
 SIGMA=      .0945       .1022 PHI1=       .0178 PHI2=       .1500

P1=    5.2000P2=    40.3129
S.F. 1=   25.4231S.F. 2=     3.2793

 IFLAG=     0
PHI=       .1350
SAFA,CAFA=       .1925      .9813
SBET,CBET=       .1762      .9844
SGAM,CGAM=       .9006      .4346
SDET,CDET=       .9009      .4341
    STOP
```

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J C Fu DATE 4/25/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 25

Tolerance Analysis (CASE A) CAPACITY = 132.2^k (CONT'D).

```
 X1=  217.1250 X2=  216.0000
 PHI=       .1530 DELTA1=       .0681 DELTA2=     1.0206
 SIGMA=      .0960      .1036 PHI1=       .0290 PHI2=       .1612

P1=    2.8438P2=   42.6656
S.F. 1=   46.4878S.F. 2=    3.0985

 IFLAG=     0
PHI=      .1530
SAFA,CAFA=       .1936      .9811
SBET,CBET=       .1751      .9845
SGAM,CGAM=       .9006      .4346
SDET,CDET=       .9009      .4340
    STOP

 X1=  217.2500 X2=  216.0000
 PHI=       .1710 DELTA1=       .0116 DELTA2=     1.0773
 SIGMA=      .0971      .1048 PHI1=       .0402 PHI2=       .1724

P1=     .4824P2=   45.0233
S.F. 1=  274.0341S.F. 2=    2.9363

 IFLAG=     0
PHI=      .1710
SAFA,CAFA=       .1947      .9809
SBET,CBET=       .1740      .9847
SGAM,CGAM=       .9006      .4346
SDET,CDET=       .9010      .4338
    STOP

 X1=  217.3750 X2=  216.0000
 PHI=       .1840 DELTA1=      -.0473 DELTA2=     1.1363
 SIGMA=      .0969      .1093 PHI1=       .0518 PHI2=       .1840

P1=   -1.9740P2=   47.4760
S.F. 1=  -66.9695S.F. 2=    2.7846

 IFLAG=     0
PHI=      .1840
SAFA,CAFA=       .1958      .9807
SBET,CBET=       .1729      .9849
SGAM,CGAM=       .9007      .4345
SDET,CDET=       .9010      .4337
    STOP
```

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/25/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance SHEET NO. 26

Tolerance (CASE A) Capacity = 160^k

```
  X1=  216.0000 X2=  216.0000
  PHI=     0.0000 DELTA1=        .5435 DELTA2=        .5435
  SIGMA=     0.0000     0.0000 PHI1=     -.0661 PHI2=       .0661

 P1=   22.7692P2=   22.7692
 S.F. 1=    7.0270S.F. 2=    7.0270

  IFLAG=     0
 PHI=     0.0000
 SAFA,CAFA=        .1844      .9828
 SBET,CBET=        .1844      .9828
 SGAM,CGAM=        .9003      .4352
 SDET,CDET=        .9003      .4352
     STOP

  X1=  216.1250 X2=  216.0000
  PHI=      .0070 DELTA1=       .5221 DELTA2=       .5651
  SIGMA=      .0933       .1009 PHI1=     -.0617 PHI2=       .0705

 P1=   21.8635P2=   23.6719
 S.F. 1=    7.3181S.F. 2=    6.7591

  IFLAG=     0
 PHI=      .0070
 SAFA,CAFA=        .1848      .9828
 SBET,CBET=        .1840      .9829
 SGAM,CGAM=        .9004      .4350
 SDET,CDET=        .9004      .4351
     STOP

  X1=  216.2500 X2=  216.0000
  PHI=      .0250 DELTA1=       .4664 DELTA2=       .6210
  SIGMA=      .0961       .1037 PHI1=     -.0506 PHI2=       .0816

 P1=   19.5256P2=   26.0068
 S.F. 1=    8.1944S.F. 2=    6.1522

  IFLAG=     0
 PHI=      .0250
 SAFA,CAFA=        .1859      .9826
 SBET,CBET=        .1829      .9831
 SGAM,CGAM=        .9005      .4349
 SDET,CDET=        .9004      .4350
     STOP
```

CALCULATION SHEET

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/25/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F. vs Rope Tolerance SHEET NO. 27

Tolerance Analysis (CASE A) CAPACITY = 160^k (CONT'D)

```
 X1=  216.3750 X2=  216.0000
 PHI=        .0430 DELTA1=        .4107 DELTA2=        .6769
 SIGMA=       .0988       .1064 PHI1=       -.0394 PHI2=        .0928

 P1=   17.1870P2=   28.3424
 S.F. 1=     9.3094S.F. 2=     5.6452

  IFLAG=     0
 PHI=        .0430
 SAFA,CAFA=        .1870       .9824
 SBET,CBET=        .1818       .9833
 SGAM,CGAM=        .9005       .4348
 SDET,CDET=        .9005       .4348
     STOP

 X1=  216.5000 X2=  216.0000
 PHI=        .0620 DELTA1=        .3518 DELTA2=        .7360
 SIGMA=       .0938       .1014 PHI1=       -.0276 PHI2=        .1046

 P1=   14.7167P2=   30.8095
 S.F. 1=    10.8720S.F. 2=     5.1932

  IFLAG=     0
 PHI=        .0620
 SAFA,CAFA=        .1882       .9821
 SBET,CBET=        .1807       .9835
 SGAM,CGAM=        .9005       .4348
 SDET,CDET=        .9006       .4346
     STOP

 X1=  216.6250 X2=  216.0000
 PHI=        .0800 DELTA1=        .2959 DELTA2=        .7921
 SIGMA=       .0962       .1038 PHI1=       -.0164 PHI2=        .1158

 P1=   12.3748P2=   33.1483
 S.F. 1=    12.9295S.F. 2=     4.8268

  IFLAG=     0
 PHI=        .0800
 SAFA,CAFA=        .1892       .9819
 SBET,CBET=        .1796       .9837
 SGAM,CGAM=        .9006       .4347
 SDET,CDET=        .9007       .4345
     STOP
```

GPD-2706 8/76 (ED-69)

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-13 REV. NO. 0

ORIGINATOR J.C. Fu DATE 4/29/83 CHECKED WS DATE 4/29/83

PROJECT TMI-2 JOB NO. 15737

SUBJECT Missile Shield Rigging - S.F vs Rope Tolerance Analysis (Case A) SHEET NO. 28

VERIFICATION OF PROGRAM "ROPE" VERSION 2.

$l_1 = 216.25 \quad l_2 = 216.0$ (Page 35)

Solution: $\phi = 0.025. \quad \phi_1 = -.0506. \quad \phi_2 = 0.0816.$

$\Delta_1 = .4664 \quad \Delta_2 = .6210.$

$P_1 = 19.5256, \quad P_2 = 26.0068$

$S.F_1 = 8.1944 \quad SF_2 = 6.1522.$

$$\Sigma Y = 82 - 2K_1\Delta_1 \sin\gamma - 2k_2\Delta_2 \sin\delta = 82 - 2\frac{.72\times 12.6\times 10^3}{216.25+.4664}(.4664)(.9005)$$

$$-2\frac{.72\times 12.6\times 10^3}{216.00+.6210}(.6210)(.9004) = 0.$$ O.K

$$\Sigma M = 204K_1\Delta_1\cos\gamma\sin\alpha - 36K_1\Delta_1\cos\gamma\cos\alpha$$

$$+36k_2\Delta_2\cos\delta\cos\beta - 204k_2\Delta_2\cos\delta\sin\beta$$

$$= \frac{.72\times 12.6\times 10^3}{216.25+.4664}(.4664)(.4349)(204\times .1859 - 36\times .9826)$$

$$+\frac{.72\times 12.6\times 10^3}{216+.6210}(.6210)(.4350)(36\times .9831 - 204\times .1829) =$$

$$= -0.07 \approx 0.$$ O.K

$$(l_1+\Delta_1)\sin\gamma = (216.25+.4664)(.9005) = 195.15$$

$$(l_2+\Delta_2)\sin\delta = (216.0+.6210)(.9004) = 195.05 \approx 195.15$$ O.K.

$$P_1 = K_1\Delta_1 = \frac{.72\times 12.6\times 10^3}{216.25+.4664}(.4664) = 19.52$$ O.K

$$S.F_1 = 160/P_1 = 8.195$$ O.K

$$P_2 = k_2\Delta_2 = \frac{.72\times 12.6\times 10^3}{216+.6210}(.6210) = 26.007$$ O.K.

$$S.F_2 = 160/P_2 = 6.152$$ O.K

memo
from R. W. JACKSON

TO: JWT

This is the documentation for the MT of the welds on the P.C. load test rig.

RWJ
4/29

QUALITY ASSURANCE MODIFICATIONS/OPERATIONS
QUALITY CONTROL PLANT INSPECTION REPORT

Unit No. II Inspector Donald Jackson PIR No UE-93017/83

Inspection Description Polar Crane - Head Lift Load Test Assembly Dwg. 2-COP-1301 Rev 1 12-13-82

Method: Visual: [X] Direct Measurement: [ ] Document Review: [ ] Other: [X] M.T.

References:

Title	Rev.	Date	Verified
Job Number 13587 WAN 54952	—	—	DJackson
MPT-1-NP	2	3-30-82	DJackson

Vendor/Item Identification (as appropriate)	Item/Characteristic/Activity To Be Inspected	Accept/Reject Criteria	Inspection Results/Readings	Compliance Sat	Compliance Unsat	Compliance Not Applic.
Load Test Assembly	V.T. Final Weld Pass	AWS D.1.1 '82 3.6.1 Thru 3.6.4 9.25	Acceptable * See Comments	DJ		

Q. A. RECORD

ORIGINAL COPY

QUALITY CONTROL PLANT INSPECTION REPORT

PIR No. LE-43017/83

Vendor/Item Identification (as appropriate)	Item/Characteristic/ Activity To Be Inspected	Accept/ Reject Criteria	Inspection Results/ Readings	Sat	Unsat	Not Applic.

Measuring and Test Equipment Used

Identification of Equipment	Serial No.	Calibration Date Due
Magna Magic M.T. Machine	3602	10-17-83

MNCR Issued: Yes [ ] No [X] QDR Issued: Yes [ ] No [X]

MNCR QDR No.	Date	Reason for Issue	Hold/Condit. Release Tag Nos. Issued
		N/A	

Comments/Other Information: * Magnetic Particle Examinations performed on Lifting Eye Welds. Results and Acceptance were Concurred by Ed Woltner

This PIR is for information only as the Job is classified Not Important To Safety

Inspected By: Donald [illegible] Hipple Date: 1-20-83

Reviewed and Approved By: [illegible] Date: 2/8/83

Distribution (X) Manager Admin. and Services Unit II (Orig.)
( ) QA Mod/Ops Manager
( ) QC Manager
(X) File

Others: (X) Tim J. Bedlington
(X) Ed Woltner
( )
( )

PIR WE-43017/83

NDT REPORT

DATE 1-20-83

TEST TYPE: LIQ. PEN. NA MAG. PART. X UT NA

TEST PROC. NO. MPT-1-NP (1) 3-30-82 MATERIAL OR EQUIPMENT USED Magna Magic 360 Cal Due 10-22-83 Red 8A Magna Flux Powder

WELD DATA

SYSTEM (Polar Crane) Head Lift Load Test Assembly DWG. NO. 2-MOP-1301 (△) WELD MAP NO. NA

ENG. SPEC. NO. NA WELD SPEC. NA CLASS NA

P. NO. NA BACK RING NA CONSUMABLE INSERT NA

ELECTRODE TYPE NA F-NO. NA INITIALS OF INSPECTION TECH. DGJ

Weld Joints No.	Welder	Symb.	W.T.	Pipe Size	Mat.	Joint Type	Root	Intermediate	Cover	Final	Within Code	Beyond Code
Lifting Eye Welds	—	—	—	—	C.S.	Partial Penetration	—	—	—	✓	✓	

M.T. Interpretation concurred by Ed Woltner

INDICATION DESCRIPTION: Slight Lamination was found on The outside edge of (2) Lifting Lugs. M.T. Examination of all Lifting Lugs determined no farther Laminations.

Donald Jackson

Thomas W. Kuntz

Q. A. RECORD

ORIGINAL COPY

DOCUMENT NO. [illegible]

CALCULATION COVER SHEET

PROJECT TMI-2 JOB NO. 15737 CALC. NO. C-1-9

SUBJECT MISSILE SHIELD RIGGING - WIRE ROPE LENGTH TOLERANCE ANALYSIS - CASE C

ORIGINATOR Francis M Fahey Jr DATE 4-25-83

CHECKER C. IANNI DATE 4-29-83 NO OF SHEETS 10

RECORD OF ISSUES									
NO.	DESCRIPTION	BY	DATE	CHKD	DATE	APPRD	DATE	ACCEPT-ANCE	DATE
0	ISSUED FOR USE	fmf	4-25-83	CJI	4-29-83	JM	5-3-83		

☐ PRELIMINARY CALC.
☐ SUPERSEDED CALC.
☐ COMMITTED PRELIMINARY CALC.
☒ FINAL CALC.

NO COMPUTER PROGRAMS WERE USED IN THIS CALCULATION

GPD-2784 Rev. 10/78 (ED-11)

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED [illegible] DATE 4-19-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT MISSILE SHIELD RIGGING - WIRE ROPE LENGTH SHEET NO. 1

TOLERANCE ANALYSIS CASE B.

OBJECTIVE :

THE OBJECTIVE OF THIS CALCULATION IS TO DEMONSTRATE THAT EVEN IF RELATIVELY LARGE ROPE LENGTH DIFFERENCES ARE ASSUMED A FACTOR OF SAFETY OF AT LEAST 5 IS MAINTAINED FOR EACH OF THE 1¼" DIAMETER WIRE ROPES. THE WIRE ROPES FORM A PAIR OF TWO-LEG BRIDLES. USED TO LIFT THE REACTOR AND PRESSURIZER MISSILE SHIELDS, THIS OBJECTIVE WILL BE DEMONSTRATED USING BASIC GEOMETRY TO ANALYZE THE ROTATION OF THE MISSILE SHIELD IF ROPES OF DIFFERENT LENGTHS ARE USED TO LIFT THE SHIELD. (SEE PLAN SHT. #3)

ASSUMPTIONS :

1. ASSUME THAT THERE ARE TWO DIFFERENT ROPE LENGTHS (TWO SHORT & TWO LONG ROPES)

2. ASSUME BOTH SHORT ROPES ARE ON THE SAME SIDE OF THE MISSILE SHIELD (SEE PLAN VIEW ON SH. #3 FOR ROPE ORIENTATION)

3. WIRE ROPE IS 6 X 37 CLASS , IWRC, IMPROVED PLOW STEEL, WITH A MINIMUM BREAKING STRENGTH OF 66.1 TONS, (PER DWG. 2-COP-1302, REV. 2)

4. THE REACTOR MISSILE SHIELD WEIGHS 41 TONS.

5. MISSILE SHIELD IS A RIGID BODY.

CALCULATION COVER SHEET

PROJECT TMI -2 JOB NO. 15737 CALC. NO. C-1-8

SUBJECT MISSILE SHIELD RIGGING - WIRE ROPE LENGTH TOLERANCE ANALYSIS CASE B.

ORIGINATOR CYNTHIA IANNI DATE 4-18-83

CHECKER Francis M Fahey Jr DATE 4-19-83 NO OF SHEETS 10

RECORD OF ISSUES									
NO.	DESCRIPTION	BY	DATE	CHKD	DATE	APPRD	DATE	ACCEPT-ANCE	DATE
0	ISSUED FOR USE	CJI	4-18-83	fmf	4-19-83	JM	5-3-83		

☐ PRELIMINARY CALC. ☐ COMMITTED PRELIMINARY CALC.

☐ SUPERSEDED CALC. ☑ FINAL CALC.

COMPUTER USAGE: NO BECHTEL OR NON-BECHTEL COMPUTER PROGRAMS USED.

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED [initials] DATE 4-19-83

PROJECT TMI - 2 JOB NO. 15737

SUBJECT SHEET NO. 1A

ASSUMPTIONS (CONTINUE)

6. THE CALCULATIONS FOR CASE B USE A 2-DIMENSIONAL ANALYSIS. A 3-DIMENSIONAL ANALYSIS WAS FIRST CONSIDERED, HOWEVER, THE DIFFERENCE IN THE RESULTING ROPE TENSIONS WAS FOUND TO BE INSIGNIFICANT. SINCE THE DIFFERENCE IN ROPE LENGTHS WERE SHOWN TO BE VERY LARGE BEFORE A S.F. OF 5 WAS EXCEEDED, THE 2-DIMENSIONAL ANALYSIS IS CONSIDERED SUFFICIENT.

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED fmf DATE 4-19-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT ______ SHEET NO. 2

REFERENCES :

1. DRAWINGS

a) BECHTEL DWG. 2-COP-1302, REACTOR BLDG. POLAR CRANE LOAD CELL AND MISSILE SHIELD RIGGING AND MISSILE SHIELD STORAGE SUPPORTS. (REV. 2)

b) BURNS AND ROE DWG. NO. 4156, REACTOR BLDG. PRIMARY & SECONDARY SHIELDS PLAN AT EL. 376'-4" & 371'-10" (REV. 6)

2. BECHTEL CALCULATIONS :

a) MISSILE SHIELD RIGGING - WIRE ROPE LENGTH TOLERANCE ANALYSIS CASE C, CAL. NO. C-1-9, REV. 0

b) MISSILE SHIELD RIGGING - SAFETY FACTORS VS ROPE TOLERANCE, CASE A, CAL. NO. C-1-12, REV. 0

c) COMPUTER PROGRAM DEVELOPED FOR MISSILE SHIELD RIGGING ANALYSIS - SAFETY FACTOR VS ROPE TOLERANCE, CASE A, CAL. NO. C-1-13, REV. 0

CALCULATION SHEET

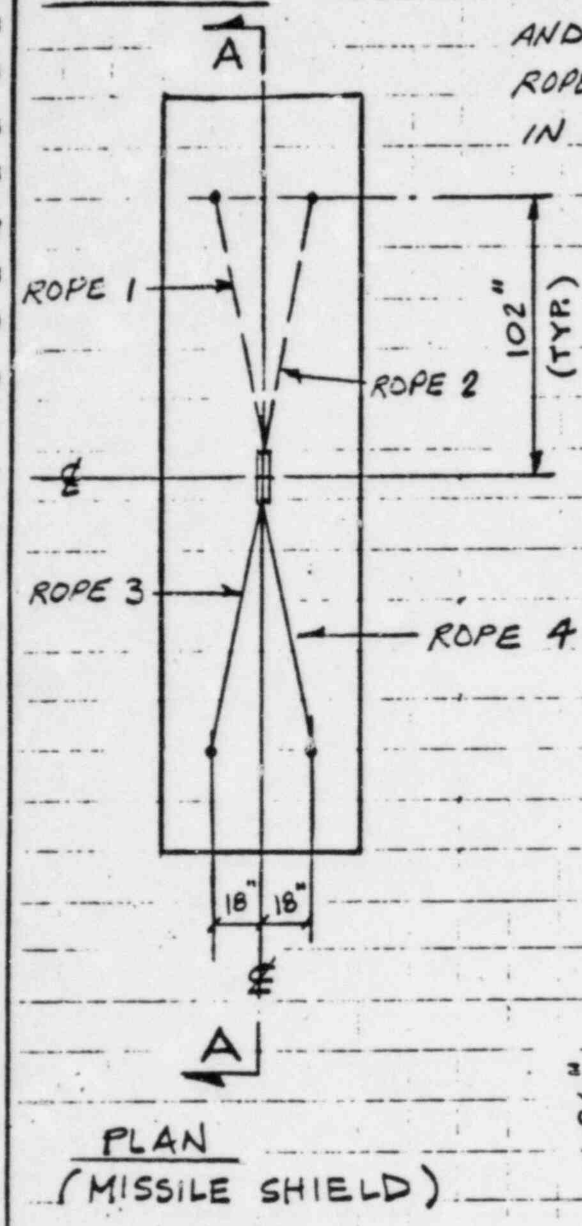
CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED fmf DATE 4-19-83

PROJECT TMI-2 JOB NO. 15737

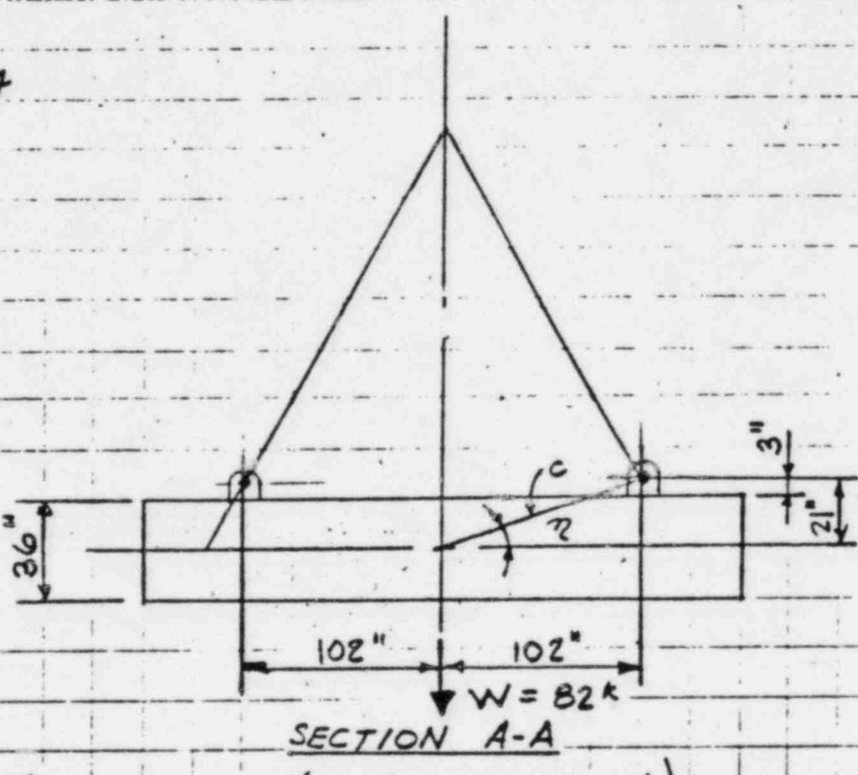
SUBJECT ______ SHEET NO. 3

CASE B : ASSUME ROPES 1 & 2 ARE EQUAL IN LENGTH AND THAT THEY ARE SHORTER THAN ROPES 3 & 4. ROPES 3 & 4 ARE EQUAL IN LENGTH.



PLAN
(MISSILE SHIELD)

— — — SHORT ROPE
——— LONG ROPE



SECTION A-A
(INTIAL CONDITION)

FOR A F.S. = 5, THE MAX. LOAD / ROPE IS :
(FROM REF. # 1):
BREAKING STRENGTH = 66.1 TONS,
MECH. EYE SPLICE AT ENDS OF ROPE HAVE A MIN. EFFICIENCY OF 92.5 %

$\therefore \quad T_{MAX} = \dfrac{.925 \times 66.1 \times 2}{5} = 24.46^{k}/_{ROPE}$

$\tan \eta = \dfrac{21}{102} = .20588 \Rightarrow \eta = 11.6336°$

$c = (102^2 + 21^2)^{1/2} = 104.1393"$

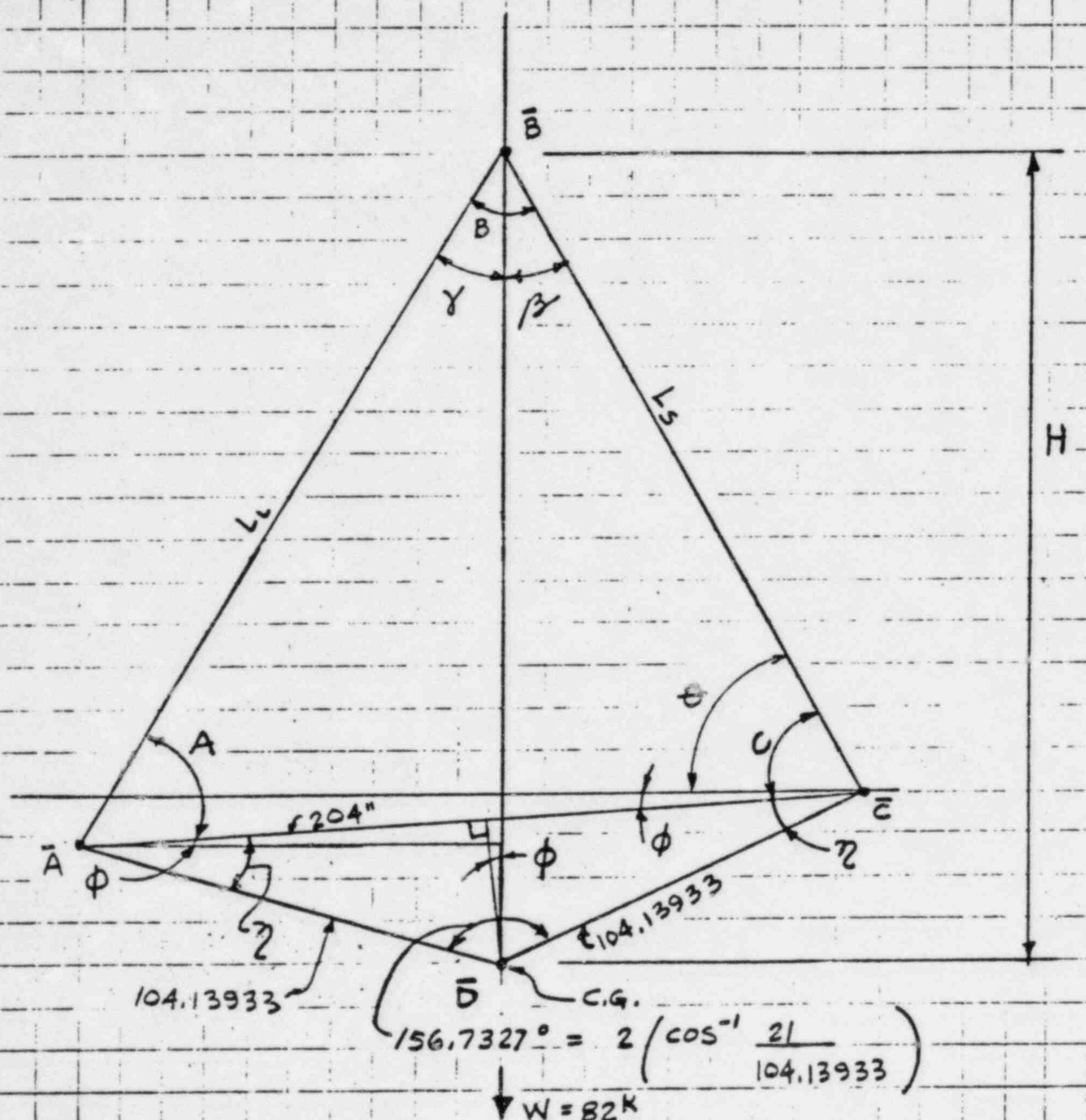
CALCULATION SHEET

CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED [illegible] DATE 4-19-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT SHEET NO. 4



FINAL CONDITION

L_S = LENGTH OF SHORT ROPES
L_L = LENGTH OF LONG ROPES

F_S = FORCE IN TWO SHORT ROPES
F_L = FORCE IN TWO LONG ROPES

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED [initials] DATE 4-19-83

PROJECT TMI-2 JOB NO. 5737

SUBJECT SHEET NO. 5

METHOD FOR SOLVING GEOMETRY AND FORCES ON ROPES

STEP 1. - CONSIDER TRIANGLE $\bar{A}, \bar{B}, \bar{C}$ SHT. #4, BY THE LAW OF COSINES.

$$\cos C = \frac{L_s^2 + 204^2 - L_L^2}{408\, L_s} \qquad \text{(EQ. 1)}$$

$$\cos A = \frac{L_L^2 + 204^2 - L_s^2}{408\, L_L} \qquad \text{(EQ. 2)}$$

$$\cos B = \frac{L_s^2 + L_L^2 - 204^2}{2 L_s L_L} \qquad \text{(EQ. 3)}$$

STEP 2. - CONSIDER TRIANGLE $\bar{B}, \bar{C}, \bar{D}$ SHT. #4, BY THE LAW OF COSINES

$$H = \left[L_s^2 + 104.13933^2 - 208.27866\, L_s \cos(C + \gamma) \right]^{1/2} \qquad \text{(EQ. 4)}$$

AND THE $\cos\beta = \dfrac{104.13933^2 - L_s^2 - H^2}{-2 L_s H}$ (EQ. 5)

$\therefore \gamma = B - \beta$ (EQ. 6)

CALCULATION SHEET

BECHTEL

CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED fmz DATE 4-19-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT SHEET NO. 6

STEP 3. - SUM FORCES IN THE VERTICAL & HORIZONTAL DIRECTIONS

$$\Sigma F_H = 0 = -F_L \sin\gamma + F_S \sin\beta$$

$$\Sigma F_V = 0 = 82^k - F_L \cos\gamma - F_S \cos\beta$$

SOLVE TWO SIMULTANEOUS EQUATIONS FOR F_L & F_S :

$$F_L = \frac{82^k}{\left(\frac{\sin\gamma}{\sin\beta}\right) \times \cos\beta + \cos\gamma} \qquad \text{(EQ. 7)}$$

$$F_S = F_L \left(\frac{\sin\gamma}{\sin\beta}\right) \qquad \text{(EQ. 8)}$$

CALCULATION SHEET

CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED fmf DATE 4-19-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT SHEET NO. 7

EXAMPLE : GIVEN $\Rightarrow$ $L_s = 205''$, $L_L = 207''$

EQ. 1 $\cos C = \dfrac{205^2 + 204^2 - 207^2}{408 \times 205} = .48770923$, $C = 60.81°$

EQ. 2 $\cos A = \dfrac{207^2 + 204^2 - 205^2}{408 \times 207} = .502510183$, $A = 59.83°$

EQ. 3 $\cos B = \dfrac{205^2 + 207^2 - 204^2}{2 \times 205 \times 207} = .509697184$, $B = 59.36°$

EQ. 4 $H = \left[205^2 + 104.13933^2 - 208.27866 \times 205 \cos(60.81 + 11.6336)\right]^{1/2}$

$= 199.977''$

EQ. 5 $\cos \beta = \dfrac{104.13933^2 - 205^2 - 199.977^2}{-2 \times 205 \times 199.977} = .868036415$,

$\beta = 29.7688°$

EQ. 6 $\gamma = 59.36 - 29.7688° = 29.5912°$

EQ. 7 $F_L = \dfrac{82^k}{\left(\dfrac{\sin 29.5912}{\sin 29.7688}\right) \times \cos 29.7688 + \cos 29.5912} = 47.32^k$

EQ. 8 $F_S = 47.32^k \left(\dfrac{\sin 29.5912}{\sin 29.7688}\right) = 47.06^k$

BECHTEL

CALCULATION SHEET

CALC. NO. C-1-8 REV. NO. 0

ORIGINATOR C. IANNI DATE 4-18-83 CHECKED [illegible] DATE 4-19-83

PROJECT TMI-2 JOB NO. 15737

SUBJECT SHEET NO. 8

FOR 2 ROPES : $F_{allow.} = 2(24.46^{K}) = 48.92^{K}$

F_L = LOAD ON 2 LONG ROPES
F_S = LOAD ON 2 SHORT ROPES

L_S (IN.)	L_L (IN.)	$\Delta = L_L - L_S$ (IN.)	∡ C (DEG.)	∡ A (DEG.)	∡ B (DEG.)	$C + \eta$ (DEG.)	H (IN.)	β (DEG.)	γ (DEG.)	F_L (KIPS)	F_S (KIPS)
205	207	2	60.81	59.83	59.36	72.4436	199.977	29.7688	29.5912	47.32	47.06
↓	209	4	61.46	59.51	59.03	73.0936	201.13	29.6957	29.3343	47.38	46.85
	211	6	62.11	59.18	58.71	73.7436	202.28	29.6198	29.0902	47.43	46.65
	213	8	62.77	58.85	58.39	74.4036	203.45	29.5398	28.8502	47.47	46.46
	215	10	63.43	58.51	58.06	75.0636	204.61	29.4570	28.603	47.52	46.26
	217	12	64.09	58.18	57.73	75.7236	205.77	29.3714	28.3586	47.57	46.06
	219	14	64.75	57.85	57.40	76.3836	206.93	29.2830	28.117	47.61	45.87
	221	16	65.41	57.51	57.08	77.0436	208.08	29.1920	27.888	47.64	45.69
	223	18	66.08	57.18	56.74	77.7136	209.25	29.0969	27.6431	47.69	45.50
	225	20	66.75	56.84	56.41	78.3836	210.41	28.9992	27.4108	47.72	45.32
	227	22	67.42	56.50	56.08	79.0536	211.57	28.8988	27.1812	47.75	45.14
	229	24	68.10	56.16	55.74	79.7336	212.74	28.7943	26.9457	47.79	44.96
	241	36	72.21	54.09	53.70	83.8436	219.75	28.1097	25.5903	47.94	43.95
	253	48	76.42	51.97	51.61	88.0536	226.76	27.3217	24.2883	48.02	43.03
	265	60	80.77	49.78	49.45	92.4036	233.80	26.4256	23.0244	48.03	42.21

CONCLUSION:

THE DIFFERENCE IN THE LENGTHS OF THE TWO PAIRS OF ROPE MUST BE VERY LARGE (GREATER THAN 5') TO EXCEED A F.S. = 5.

GPD-2706 8/76 (ED-69)

GPU Nuclear

GPU Nuclear
100 Interpace Parkway
Parsippany, New Jersey 07054
201 263-6500
TELEX 136-482
Writer's Direct Dial Number
(201)-263-6290

June 9, 1983
4410-83-L-0116

TMI Program Office
Attn: Dr. B. J. Snyder
Program Director
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Sir:

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Allegation Investigation

On March 4, 1983, the Company initiated an investigation into various allegations expressed by Mr. Larry P. King, Jr., the Site Operations Director at TMI-2. The investigation was conducted for the Company by Mr. William W. Lowe of Pickard, Lowe & Garrick, Inc. and Dr. Roger W. Griebe, then with Energy Inc., and currently with Aisling Inc.

I am forwarding the report of their investigation and the Company response to that report.

> Attachment 1 is the letter to Mr. Lowe which defines their charter for the investigation. Dr. Griebe received a similar letter.
>
> Attachment 2 is their report to me dated April 25, 1983.
>
> Attachment 3 is the Company's response dated June 8, 1983, to that report.

The report states:

> "To start with, as far as we can determine, there are no allegations that actual physical operations have been unsafe. Nor have we found evidence that they have been. Rather, the issues are whether technical analyses, procedures and practices are adequate to keep them safe, particularly in respect to use of the polar crane."

GPU NUCLEAR

TMI Program Office
Attn: Dr. B. J. Snyder
Program Director

June 9, 1983
4410-83-L-0116

As indicated in the June 8 letter (top of page 5), the Company will be providing some additional information in response to recommendations contained within the report. That supplementary information will be forwarded to you when it becomes available.

Sincerely,

RCArnold

R. C. Arnold
President

cc: Mr. L. H. Barrett
Deputy Program Director -
TMI Program Office
w/enclosures

Mr. B. K. Kanga, wo/enclosures

Attachments

1 R. C. Arnold letter, March 4, 1983, to William Lowe, Pickard, Lowe & Garrick, w/att, R. C. Arnold letter, March 4, 1983, to Mr. L. P. King

2 William W. Lowe letter, April 25, 1983, w/att report of William W. Lowe & Dr. Roger W. Griebe, same date

3 R. C. Arnold letter, June 8, 1983 to William W. Lowe and Dr. Roger W. Griebe, w/enclosures