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MAY 29 1997
DOE-0994-97

Steve Fink
U.S. Army Corps of Engineers
201 North Third Avenue
Walla Walla, WA 99362-9265

Dear Mr. Fink:

TRANSMITTAL OF COMMENTS ON THE DRAFT ENVIRONMENTAL MANAGEMENT-PHASE 2 REPORT

The purpose of this letter is twofold. First, I would like to express my appreciation with your team's effort in evaluating the scope and preconceptual cost for Operable Unit 4 (OU4), at the Department of Energy, Fernald Environmental Management Project (DOE-FEMP), as part of Project Environmental Management (EM)-Phase 2 to identify project improvements and potential cost savings.

Secondly, this letter transmits the DOE-FEMP's comments on the draft Project EM-Phase 2 Report, *Fernald Environmental Management Project Critical Analysis of Operable Unit 4 Vitrification and Potential Alternatives*. Please revise the report to address these comments or incorporate them as a separate enclosure to the report.

If you have any questions concerning the enclosed comments, please contact Dave Yockman at (513) 648-314, or me at (513) 648-3101.

Sincerely,

Glenn Bridgitts

for Jack R. Craig
Director

FEMP:Yockman

Enclosure: As Stated

Recycled and Recyclable

cc w/enc:

S. Farrell, EM-1
V. Fayne, EM-40
J. Fiore, EM-40
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N. Akgunduz, DOE-FEMP
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B. Heck, FDF/52-3

Review of Project EM - Phase 2 Report "Fernald Environmental Management Project Critical Analysis of Operable Unit 4 Vitrification and Potential Alternatives		
Page	**Reference**	**Comment**
Gen		Throughout the document, many references are made to the cost estimates as the baseline cost estimate. It should be noted that the cost estimates presented for IRT's review (and for the Project EM's review) were Pre-Conceptual and were not reviewed by DOE.
Gen		Suggest presenting the cost benefits as whole numbers in ranges (e.g., 30 to 60% waste loading to show the range of cost with different waste loading) or qualifying the confidence associated with the cost benefits identified by the VE team. This will account for uncertainty in the proposed recommendations and their associated cost savings which are based largely on professional experience of the cost estimator.
Gen		Suggest including discussion of impacts (schedule & cost) of amending the Record of Decision to stabilization. At a minimum it is suggested these impacts should be acknowledged in the executive summary.
Gen		Recommend that discussion on percentage of waste loading include discussion that cementation studies to date have only established the ability to achieve 20% waste loading for silos 1 and 2 and that additional studies at higher waste loading should also be performed based on industry experience.
Gen		As stated in the section 4.3.4, the VE study team assumed the pre-conceptual level cost estimates provided were accurate. Considering the assumptions by the VE team, the cost benefits identified throughout the document should be prefaced or noted as "potential cost benefits" and "approximations."

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Page	**Reference**	**Comment**
Gen		Throughout the document, references are made to "validating" the ROD and cost estimates. The Project EM was not asked to "validate," but was asked to review and assess the reasonableness of the cost estimates presented for review. It is recognized that the cost estimates were not prepared to be able to endure the "validation" process. Please reword where applicable.
1	4th paragraph, 2nd bullet	Suggest revising to read: "Review the pre-conceptual cost estimates provided by FDF for the FS and the IRT Study, and assess the reasonableness of latest technical basis and assumptions.
1	Executive Summary 4th paragraph 1) "...assess the validity of..."	Project EM was not requested to 'validate" the ROD. Suggest changing the word "validity" to implementability/viability and adding to the end of the sentence: within a reasonable time and cost."
1	Executive summary 2nd paragraph	Please provide a description of what a "CA" is and how it applies to OU4 (perhaps introduce the statement here to include what the current selected remedy is in the existing ROD for the reviewers who are not familiar with OU4).
2	third bullet	The assumptions used to estimate waste volumes are based on treatability studies performed to date. Suggest adding - Additional treatability test should be performed to determine the optimum waste volumes.
2	3) VE Study Results, fourth bullet	May be more expensive than baseline. As a result of our discussions on 4/30/97 we all agreed this recommendation would be difficult to implement and would likely be more costly than current baseline approach. Recommend deleting, but maintaining in Appendix as a proposal that was evaluated.

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Page	Reference	Comment
2	2nd bullet	May be so, but at a higher cost for interim storage. Suggest indicating that although cementation has a faster processing rate it will require interim storage.
2	3) 7th bullet pg 23, 5.,2) C-20, Recommendation A1.2	All discussions on the Radon Treatment System should be revisited. Alternatives 2 and 3 currently require 2 process and handling and treatment systems (i.e. one for the Silos 1 & 2 treatment facility and one for the Silo 3 treatment facility). In addition, the current baseline includes an upgrade to the existing radon treatment system for the purpose of reducing worker exposure during work near the silos prior to treatment (e.g. retrieval of samples for vendor proof of process testing). The recommendation to construct one solidification facility should already include one process air handling treatment system. Therefore, consider moving discussion and references of using only one air handling and treatment system to recommendation C5.4
2	Bullets	Add 4th bullet to the top of the page which discusses the experience and knowledge gained from FN VitPP.
2	Section 2)	This paragraph needs to be revisited based on discussions held with VE Study team, DOE, and FDF. Needs to be clear that this was separate evaluation and not additive. Per verbal discussions on 5/1/97 we agreed to delete $118 million (24%).
2	3), 5th bullet and page 23, 5., recommendations, 8th paragraph	Suggest modifying to read: <u>utilize one turnkey contractor to design, construct, and operate</u> one batch....

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Page	Reference	Comment
2	Section 3)	Per verbal discussions on 5/1/97 we agreed to reword 1st paragraph as follows: -The project EM team identified potential cost benefits of up to $330.5 million for implementing solidification for all silo waste if the suggestions can be successfully implemente. This includes the following cost reducing recommendations. -Bullets need to be reworded as potential cost savings. -It would be very useful if cost reducing recommendations were put in tabular form and also included pros & cons associated with the implementation of each recommendation to realize the potential cost benefits (e.g. safety, additional or modifications of design, public acceptance, etc).
2	2nd bullet, "...at the same rate for both..."	Please clarify if it was the rate or duration.
2	3rd bullet, '...to estimate waste volumes..."	Suggest correcting to say "...to estimate treated waste volumes."
3	2nd bullet	Revisit to make sure the potential delay of Silo 3 remediation is considered and discussed. The way it is written may be interpreted as delaying remediation of Silo 3 until the path forward is resolved for Silos 1 & 2.
4	1.2, 2) "Validating the.."	Suggest changing the word "Validating" to "assess implementability/viability of..."
6	2.3.2 2nd sentence	Suggest adding ...for fiscal year 1996 (FY) and was a pre-conceptual cost and schedule estimate prepared by...

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Page	**Reference**	**Comment**
8	section 3 2nd line "...OU4 are mixed low-level wastes..."	Suggest revisiting based on the following comment: Needs to be consistent in describing the Silo wastes. The wastes are not mixed low level waste. Based on the classification of the material in the silos they are 11(e)2 byproduct, however the material is very similar to a mixed low level waste.
10	3rd paragraph, last sentence Table 1 shows baseline cost estimates at the time...	Suggest modifying sentence to read: "Table 1 shows the pre-conceptual cost estimates available...
10	Table 1 Total Analyzed Cost	Verify
11	4.1.1 3rd paragraph 2nd sentence, ...several times larger than any existing, melter...	Suggest adding:...<u>in full scale operation to vitrify this kind of material</u> and would create a number...
11	4.1.1, 7th line, "The VitPP meltdown occurred..."	The term "meltdown" is used in nuclear reactors with fission material. The appropriate (and accurate) term for the incident is "bottom drain incident." Also, it is unclear where the supporting document is for the statement "...while vitrifying ...represents Silo 3 material." Please clarify.

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Page	**Reference**	**Comment**
11	The original Vitrification Pilot Plant basis included a cost estimate of $14.1 million,...	The $14.1M was only design and construction cost and did not include operations costs.
11	4.1.1 1st sentence	Suggest changing $66 million to $32.9 million, which are based on actuals.
11	4.1.3 3rd paragraph, last sentence	Suggest adding: Consequently, the team believes a new.... will be required prior to final treatment.
11	4.1.1 The VitPP meltdown occurred while vitrifying...Silo 3	Suggest revisiting based on following comment: Presents a biased opinion. The melter failed over time not specifically as a result of Silo 3 surrogate.
11	4.1.2, 1st paragraph, 2nd sentence	Suggest adding: IRT confirmed the FS results which concluded....
12	1st Bullet, Fernald does not have experience cementing...	Suggest modifying to read: "Over 100 cement recipes have been formulated with actual silos wastes and these were documented in a large detailed book entitled "Treatability Study Report Operable Unit 4." The formulations picked were based on industrial information and done by a vendor knowledgeable in solidification. However, experience in stabilizing the waste at the Pilot-Scale level is lacking."
12	last paragraph, 3rd sentence solidification is quicker...	Suggest revisiting to include discussion of other technical factors (e.g., metal leachability, long term durability, and Radon emanation.

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Page	**Reference**	**Comment**
13	4.1.3, 4th paragraph	Suggest replacing with the following: The data from Treatability Study Report for Operable Unit 4 included four vitrification studies (2 lab scale, 1 bench scale and 1 optimization).
13	4th paragraph, 2nd sentence and 4th bullet 4.1.3 (MAWS) melts performed to evaluate the vitrification process,..	Recommend deleting reference to MAWS since it is not directly applicable to the Silos remediation and thus not good for comparison purposes.
13	4.1.3, First 5 bullets	Suggest using the four test descriptions provided instead of the 5 bullets (which don't accurately describe the tests performed for the FS). 1. PNL study of 1989 - total amount of material 400 grams melt of 70 grams. 2. PNL study of 1990 - 7 Kg, 1 melt 968 grams, 1 melt 500 grams. 3. PNL study of 1992 - 14 Kg total screen melts 100 grams verification melts of 1 Kg each 4. PNL Optimization study 1993-1994 - remainder of 14 Kg screening melts 100 gram verification melts 1 Kg each.
13	4.1.3, 2nd paragraph, 2nd sentence	Suggest modifying to read: ...also met all criteria <u>with the exception of criteria 4 which was only partially met because the volume of treated waste was not reduced.</u>

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Page	**Reference**	**Comment**
14	4.2.1 These costs include indirect and contingency but do not include escalation or site "hotel". Table 2 summarizes the current estimated cost for remediation.	Suggest revisiting to clarify estimates
14	2nd bullet, vitrifying a rather innocuous waste.	Suggest defining what is meant by "innocuous waste" or delete the statement.
14	2nd bullet, 1st sentence 4.1.3 no...operation of a production vitrification facility	Suggest adding: ...operation of a <u>full scale</u> vitrification facility to treat waste similar to the silos waste.
15	Table 2 Vitrification Pilot Plant Costs - 12,000,000	Suggest adding: Vitrification Pilot Plant Cost <u>(Phase I Operations)</u>

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Page	Reference	Comment
15	4.2.1.1 Broad Analysis	Need to clarify
16	4.2.1.1.3 Arbitrary Cost Rounding, cost estimate have been rounded to millions of dollars and Section L.3	Suggest revisiting based on discuss with VE team on May 1, 1997 in which it was explained to the VE team the pre-conceptual cost information presented to the VE team was the same as that presented to the Independent Review Team. To facilitate the IRT review the costs were rounded to the nearest million $. These pre-conceptual cost estimates however, were developed without rounding.
18	Boundary Condition 3, 2nd paragraph, 1st sentence, An IRT recently...	Suggest modifying to read: ...requirements for the silo waste <u>and confirmed the Feasibility Study determination that both vitrification and solidification are viable treatment methods.</u>
20	1st paragraph, 3rd sentence, Evaporation is required...	Suggest revisiting based on following comments: Waste slurries do not need to be evaporated prior to vitrification. Slurries can and are fed directly to the vitrification melter. For vitrification, additional energy is required to evaporate the water contained in the slurry fed to the melter. Some moisture can help the vitrification of the K-65 wastes. Where as, evaporation, or some other pre-treatment method, to remove water may be necessary to remove the water to make cement with higher waste loading.
20	4.3.5.2, Fifth paragraph	Suggest deleting based on discussion with VE team on May 1, 1997 in which the team indicated they would delete the recommendation to remove the bentonite separately , but instead leave in as a proposal in the Appendix.
20	4.3.5.2, Fourth paragraph last sentence.	Suggest modifying to read: "The cost of packaging, shipping, and disposal decreases as the waste loading increases."
22	table 4, footnotes	Suggest reworking footnotes to make more clear.

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Page	**Reference**	**Comment**
23	5(3) and C-38, recommendation A2.2	Suggest considering discussion of the following safety concerns: Radon control? High wind hazard? Potential of dropping pump on dome? Manned access on dome?
23	5., recommendations, 5th paragraph 3) implement VE recommendation A2.2	Suggest modifying total cost benefit to include D&D see page C-49.
23	5(1) This will result in cost benefits of $46 million...	Suggest revisiting base on following comment: Very different material will require different building equipment etc. Single plant will save some (potentially) but will complex some operations dust vs. slurry; rad level? Rn generation? Changeover.
23	5., recommendations, 2nd paragraph, 1) implement alternative 3	Suggest reviewing Applied Decision Analysis (ADA) report for cost of amending Record of Decision and including in this paragraph (Attachment 1-ADA report).
23	5., recommendations, 4th paragraph 2) implement VE recommendation A1.2	Suggest deleting 2nd sentence and adding the following to the end of the last sentence: (Vitrification of Silos 1 & 2 and stabilization of Silo 3).
23	5(5)	Per discussion with VE team on 5/1/97, recommend deletion as a VE recommended proposal, but leaving in as a VE proposal in Appendix C.
24	3rd paragraph 4) treatability study should be...	Suggest adding the word cementation to the beginning of the paragraph.

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Page	**Reference**	**Comment**
24	3) 1st sentence	Suggest modifying to read: Dry retrieval methods should be revisited to validate it's feasibility ...
B-2	Pairi	Should be Paine
B-3	Griffon	Spelling: Griffon should be Griffin and Hecke should be Heck. Change DOE to FDF
C-5	Recommendation A1.1	Suggest the following note be added to disadvantages: The application of polyurethane foam in the silo headspace was thoroughly investigated and rejected on the bases of fire hazard in 1988.
C-5	Table	Suggest deleting subtotals and total. These do not add value to the report.
C-5	Recommendations A1.1	Reviewed for Removal action to reduce headspace concentrations and in Retrieval study - Found to be impractical. Therefore, suggest adding the following information to the disadvantages section: foaming the head space will result in additional waste; the foam would restrict use of the spray nozzles; moving the K-65 slurry at levels where the solids content is greater than 40% would be extremely difficult.
C-7	Recommendation A1.1, 3rd paragraph, 2nd sentence. Every pound of water added....	Suggest revisiting based on the following comment: It is anticipated that some water will be removed prior to vitrification or cementation and recycled for retrieval.

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Page	Reference	Comment
C-7	Recommendations A1.1, 2nd paragraph, 2nd sentence	Suggest revisiting based on the following comment: Calculations indicate that cutting a 6ft. hole in the top of the dome will not weaken the dome (Attachment 2- 1993 Structural Evaluation of Silos 1,2,3,and 4 With 6-foot Diameter Opening at Center Based on 1986 NDT Test Results).
C-21	Recommendations A1.2	Revisit based on the following comment: Currently evaluating the advantages of recycle vs. once thru system- note the efficiency of carbon significantly impacted by temperature and moisture content.
C-25	Disadvantages: Interruption of silo remediation would occur...	Suggest adding: <u>schedule extension due</u> to interruption of silo remediation during the time...
C-35	A2.1 Proposed $180,550	Suggest revisiting based on the following comments: 4 foundations must be constructed therefore not ½ cost Note that @ Niagara the pump was worn out after retrieval - 2 pumps would probably be required.
C-38	A2.2	Revisit recommendation to consider contamination control and stability of work platform are concerns.
C-39	A2.2 Disadvantages	Suggest adding the following bullets to disadvantages: -May increase safety risk due to operator error vs rigid structure. -Radon Control would be difficult if current concept which would allow use of Houdini for discrete object removal at the same time the pump is deployed.

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Page	**Reference**	**Comment**
C-39	A2.2, Advantages, 7th bullet (i.e., less exposure to workers).	Suggest adding: ...over silos during maintenance operations (e.g. clogged pump). In other words less exposure to workers.
C-40	A2.2, 2nd paragraph, 3rd sentence ....it is obvious the tower crane is the most appropriate choice	Suggest modifying to read: ...using their 6 criteria, the VE team believes the tower crane is the most ...
C-49	Comparison of cost	Suggest revisiting to add D&D cost to the subtotal
C-53	A2.2,Table 2, Tower Crane column	Suggest revising as follows: 5X3=15 3X3=9 4X2=8 4X2=8 5+=5+ 5+=5+ 50
C-55	C1.1 Justification: when a cost/benefit analysis is correctly performed	Suggest modifying to read: ...for low level waste has been found by the VE team to be cost prohibitive based on existing cost benefit analysis to date.

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Page	**Reference**	**Comment**
C-56	4th paragraph, 1st paragraph ...estimates for the OU4 presented in the FS were wildly optimistic..	Suggest deleting the word "wildly."

Page	Reference	Comment
C-56	3rd paragraph and General	This paragraph and the report, in general, state that the NRC 500 psi requirement is not needed because of (1) cost and (2) because the cement can pass the TCLP test without it. Recommend revisiting based on discussion below: The NCR recommends 50 to 60 psi for other waste forms except cement which is 500 psi. The Corp of Engineers recommends 50 psi (or less) for the OU4 solidified wastes. Ironically, that is why the NRC put this 500 psi restriction in the specification for cementation type waste forms to prevent one from cutting costs and making a waste form that is not durable and is not long lasting. An excerpt from the NRC, "Stabilization/Solidification of CERCLA and RCRA Wastes," February, 1991, explains this position. Portland cement mortars, which are comprised of mixtures of cement, lime, silica sand and water, are readily capable of achieving compressive strengths of 5000 to 6000 psi; that is approximately two orders of magnitude greater than the minimum compressive strength required to resist deformation under load in current low-level waste burial trenches. Therefore, to provide greater assurance that there will be sufficient cementatious material present in the waste form to not only withstand the burial loads, but also to maintain general "dimensions and form" (i.e., to not disintegrate) over time, it is recommended that cement-stabilized forms posses compressive strengths that are representative of the values that are reasonably achievable with current cement solidification processes... a mean compressive strength equal to or greater than 500 psi is recommended... This value of compressive strength is recommended as a practical strength value that is representative of the quality of cementatious material that should be used in the waste form to provide assurance that it will maintain integrity and thus posses the long term structural capability required by Part 61.

Page	Reference	Comment
C-57,	3rd paragraph.	The paragraph states that NFS made Silo 3 cements with 70 and 80 wt% waste loading. Suggest revisiting based on the following comments: What is described in the Corp of Engineers' report as waste loading is only the ratio of waste to binder and does not include the weight of the water. At a *ratio* of 70:30 (the above mentioned 70 wt%), the actual waste loading including the water is 35 wt% (see table in Attachment 3 showing the actual waste loading).
C-57	4th paragraph, ... As can be seen, on a dry weight basis, this formulation is over 94% waste loading ..."	Suggest revisiting based on the following comments: The waste loading is portrayed as too high. The report does not factor in the water used nor state the strength of the "cement." Since uranium oxide is a very dense material it gives the illusion of high waste loadings. However, if the uranium oxide, were a lighter material, like sand or K-65 material, the waste loading would only be 32 wt%. See the attached calculation. Also, lets not forget that the uranium oxide wastes contained only minor amounts of contaminants in the ppms to 100s ppm. The report does not give TCLPs before and after cementation -- maybe the uranium oxide waste passed, or came close to passing, the TCLP test and the waste was basically cemented for shipping purposes and to reduce dusting issues. It should not take much SS binders and stabilizers to contain the minor concentration of contaminants when compared to the silo wastes which contain over 150,000 ppm lead and barium. This is a 1000 times more concentrated and presents a different story.

Page	Reference	Comment
C-57	Justification,At Weldon Spring, pit material... as a conservative approach.	Suggest revisiting based on the following comments. Weldon Spring pilot plant did not produce SS grouts with waste loading ranging from 45 to 60%. The waste loadings were significantly lower than this (See Attachment 4-Figure 5.1) taken from the Weldon Spring pilot test report may be where the Corp of Engineers assumed a waste loading from 45 to 60% but is actually 19%. Calculation for the 19% follow. The test were performed with actual pit waste residues. The Weldon Spring engineers recommended ≥43% *Fresh % Solids* to consistently make greater than 50 psi SS grout. This is close to the Corps' referenced 45%. However, this is not the waste loading of the SS grout. The actual waste loading can be calculated as follows: The slurry from the thickener was made directly into the SS grout in a mixer. Dry binders were added to the slurry in the mixer. The ratio of slurry to binders in the mixer was 1 part slurry:0.3 parts binders (or 1:0.3). Therefore: SS Binders = 100 lbs(0.30) = 30 lbs The slurry contains 25 lbs waste per 100 lbs of slurry (i.e., 25 lbs waste and 75 lbs water assuming waste has zero solubility in water). See Comment 3 and Figures 1 and 2 showing thickener operation. SS grout = Slurry + binders = 100 lbs + 30 lbs = 130 lbs Fresh Solids in grout = 25 lbs + 30 lbs = 55 lbs Fresh % Solids = (55 lbs/130 lbs) x 100% = 43% (the recommended solids content by the Weldon Spring engineers)

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Page	**Reference**	**Comment**
C-75	C4.1 Disadvantages	Suggest adding the following disadvantages: Slow cooling process - requires controlled cooling, which would require a larger cooling building.
C-75	C4.1 Justification:, 2nd bullet, Better waste form	Suggest providing justification and/or reference
C-76	C4.1 Justification (continued), Schedule, 2nd sentence	Production period is 3 years not 4 years.
C-78	C4.2 Justification, 1st paragraph, last 3 sentences, Because of the beyond.... recommended changes discussion.	Suggest modifying to read: Due to the design and operating conditions, this nominal 1 ton/day development melter failed after 6 months operations with surrogate material. During this period significant information was learned about the impacts lead and sulfates have on the melter design and construction. These issues/concerns are reviewed below.
C-81	C5.1 Recommended Change: Increase waste loading...	Suggest including experience and/or references which provide a basis for this increase in waste loading. Also consider changing the Recommended Change to recommend additional waste loading studies due to the significant cost savings potential associated with packaging, transportation, and disposal. The evaluation included in this recommendation could be used to demonstrate the cost and schedule sensitivity associated with the waste loading rather than selecting a waste loading value that currently has not been validated.

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Page	Reference	Comment
C-82	C5.1 Disadvantages: None	Suggest adding the following disadvantages: -Concentration of Radioactive material is higher (possible safety concern for worker) -Concentration of metals in the waste form are higher and therefore may be more difficult to pass TCLP -Compressive strength of waste form is lower (which is currently not an issue for shipping and disposal)
C-82	C5.1, Justification:, 1st sentence, ... silo 3 apparently achieves a 45% waste loading factor. It is assumed that..	Suggest revisiting based on the following comment: Poor assumption. Silos 1 & 2 material is very different from Silo 3.
C-86	C5.2 Disadvantages:, 3rd bullet, May slightly reduce the amount...	Suggest adding to the end of the bullet: , which would result in an increase the amount of waste to be disposed of.
C-86	C5.2 Justification:	Suggest revisiting based on the following comment: This is only true if the amount of cement waste can be significantly reduced from the 20% waste loading baseline.

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Page	**Reference**	**Comment**
C-87	C5.3 Recommended Change:, 2nd sentence, Dispose of bentonite...	Suggest revisiting based on the following comment: Bentonite cap is likely to be contaminated. In addition, it is not a smooth and level layer which can be easily scraped off and therefore would likely be very difficult to retrieve without also retrieving some of the waste material.
C-88	C5.3 Advantages: Reduce by 11% the time and cost of treating,...	Suggest revisiting based on following comments: This assumes that you can get all of it and assumes cement stabilization. Not so with vitrification since 70% is water.
C-88	C5.3 Disadvantages:	Suggest adding the following disadvantages: -Waste is not layered evenly over waste and therefore will be difficult to remove without removing waste material at the same time. -Bentonite layer is likely to be contaminated and therefore would need to be handled as a mixed waste
C-89	C5.3Justification:, 4th sentence, c) the treated waste volume	Suggest revisiting based on the following comment: When vitrified will be ≈3% since the bentogrout is ≈70% water - Bentonite also provides glass former that must be added if bentonite is not present.
C-90	C5.3 Assumption 2	Suggest revisiting based on following comment: Design, build and construct and operation of a separate retrieval system for separate bentonite removal may impact schedule.
C-90	C5.3 Assumption 3	Suggest revisiting based on the following comment: Bentonite is likely contaminated and therefore must be treated as mixed waste and disposed of at NTS also.

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Page	Reference	Comment
C-93	C5.4 Recommended change, Procure...plant sized to handle the target of the 2 waste streams.	Suggest revisiting to consider the following comment: Many more factors are involved in the design than just quantity of waste. Wet vs. dry, radon vs. thorium etc.
C-94	C5.4 Justification 24 hours a day...	Suggest revisiting to consider the following comment: Current baseline considers a stakeholder concern regarding transport - assumes 10-12 trucks/day would probably be pushing the limit and therefore interim storage facilities would be required.
C-94	C5.4	Suggest acknowledging that the material in Silo 3 is very different from Silos 1 and 2 and therefore a thorough evaluation will be required to process the materials in the same facility. Note that preliminary evaluation has been performed and indicates that this is not a significant cost reduction while complexing the facility.
C-103	C5.4 Calculations 1)... Estimate equals 65% of current Silos 1 and 2.	Suggest clarifying the basis of using 65%.

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Page	**Reference**	**Comment**
C-104	D1.1	SS boxes must be hermetically sealed to prevent the leakage of radon. The boxes must withstand some minimal internal pressure because the SS reactions are exothermic which will expand gases within the boxes. If the boxes and seals cannot withstand the pressure, they will likely leak. Likewise, the boxes will want to breathe with the heat of the day and the cooling of the night. The seals on the proposed metal boxes will need to be flexible because the weight of contained concrete (at 50 psi will give little or no stability) will want to warp the box during movement and placement. Suggest revisiting this recommendation to consider the above comments.
C-104	D1.1 Recommended change	Suggest revisiting to consider the following comments: Reducing thickness increases exposure (ALARA) w/o thickness reduction waste volume is essentially the same. There are also shipping weight limits to be aware of.
C-105	D1.1 Justification: DOT requires 200 mrem/h	Suggest revisiting based on the following comment: May be ALARA problem with handling ≈10,000 packages @ 100 mrem/hr each., which may require remote handling facility.

Page	Reference	Comment
C-110 - C-114		Suggest revisiting based on the following comments: The subsequent transportation costs should be approximately 19,008,000 based on the following: 4 containers per shipment resulting in 23,760 containers X shipment/ 4 containers = 5,940 shipments. $3,200/shipment resulting in (5,940 shipments) X ($3,200/shipment) = $19,008,000. This exceeds the original design by $12,928,000 as follows: 19,008,000 - 6,080,000 = $12,928,000 Assuming a purchase cost of $800/container the cost of the quantity of containers is $19,000,000 as follows: $800/container X 23,760 containers = 19,008,000 This exceeds the recommended design costs on page C-110 by $15,124,000 as follows: 19,008,000 - 3,884,000 = $15,124,000 The required quantity of concrete needed under this scenario would require more concrete than could be made from Silo 3 material as follows: 2.4 yd^3 / container X 23,760 containers = 57,000 yd^3. Note: cemented Silo 3 waste volume is 6,088 yd^3. Using the 1300 lbs payload capacity of the container, and using a density of 173 lbs/$^{ft^3}$ for vitrified waste you would need 23,770 containers as follows: 1,300 lbs/container X 1ft^3/ 173lbs = 7.5 $^{ft^3}$/container

Review of Project EM - Phase 2 Report "Fernald Environmental Management Project Critical Analysis of Operable Unit 4 Vitrification and Potential Alternatives		
Page	**Reference**	**Comment**
C-110	D2.1 Recommended Change:, 2nd sentence, An additional consideration ...	Suggest revisiting based on the following comments: Capital cost for facility? Will it pass drop test? Perform box manufacturing operation while on an airline - ALARA.
C-110 - C-114	1) This section needs to be revised due to numerous errors which are carried through the calculations and subsequent cost estimates as follows:	The estimated concrete to be used is stated to be in the report as follows (p c113): Concrete used: Floor 5X5X0.5 = 12.5ft^3 Wall; 4X4X0.5 = 36 ft^3 = 48.5 ft^3 The concrete used does not account for a lid of similar dimension t the floor. The calculation for the wall concrete has a mathematical error (4X4X0.5 = 8). FDF has recalculated the "concrete required" pursuant the report's sketch as follows: Floor 5X5X0.5 = 12.5ft^3 Lid 5X5X0.5 = 12.5ft^3 Wall; 4X4X0.5 = 32 ft^3 = 67 ft^3 The subsequent disposal costs would be approximately $53,222,400 as follows: (23,760 containers) X (112ft^3/container)($20/ft^3 disposal cost) = $53,222,400 This exceeds the original design by $43,266,400 as follows: $53,222,400 - $9,956,000 = $43,266,400 Related pages which reference this section should be double checked.

Review of Project EM - Phase 2 Report "Fernald Environmental Management Project Critical Analysis of Operable Unit 4 Vitrification and Potential Alternatives		
Page	**Reference**	**Comment**
C-111	D2.1 Disadvantages: Need to form or place floor and walls.	Suggest adding to disadvantages: -work with alpha generating waste - potential impact to workers - concern regarding potential airborne dust. -white metal box will need to be certified to meet the transportation requirements.
C-121	E1.1 Recommended change Additional 10% (Total 50%)...	Per discussion with VE on 5/1/97 suggest deleting summary cost analysis table since it doesn't add value to the recommendation.
C-125	E2.1 Recommended Change: Delay solicitation of RFP for Silo 3...	Suggest revisiting to consider the following comments: Significant delay in processing Silo 3 - complexing contract may be difficult to get good proposal.
C-129	E2.3 Justification: ...minor modifications...	Suggest revisiting based on the following comments: Contamination and rad exposure are significant issues and therefore will likely require substantial modifications to commercial available and proven technology.
C-129	E2.3 Advantages: first bullet	Suggest revisiting to consider the following comment.: Commercial equipment will need to be modified for rad use.
C-131	E2.4 Disadvantages	Suggest adding the following disadvantage: -Control of process not within the program DOE HQ and other sites would be involved - may be a time consuming effort.

Review of Project EM - Phase 2 Report "Fernald Environmental Management Project Critical Analysis of Operable Unit 4 Vitrification and Potential Alternatives		
Page	**Reference**	**Comment**
L	All through appendix L	Estimates provided to VE team did not capture all costs in the resource loaded schedule, but rather only included costs that were re-estimated. Suggest acknowledging this in Appendix L (Resource loaded schedule data was provided separately to VE team cost estimator.

Review of Project EM - Phase 2 Report
"Fernald Environmental Management Project Critical Analysis of Operable Unit 4 Vitrification and Potential Alternatives

Page	Reference	Comment
L-1	Table L1	Revisit Table 1 based on comment below: Silo 3 stabilization cost in the presentation were based on the Silo 3 Alternative Study and are pre-conceptual design estimates The Alternative #2 Silo 3 stabilization estimate submitted to the Core of Engineers for Engineering and Construction was $11,619,341 unescalated. In the resource loaded schedule the Silo 3 stabilization is as follows: 4CBA8 Silo 3 Alternative 51,609 4CC00 Silo 3 Design 2,544,593 4CD00 Silo 3 Construction 7,606,553 4CCB1 Silo 3 RFP/Bid Award 720,588 4CCB2 Silo 3 Treatability 242,344 11,165,687 * The operation cost in the Core of Engineering report $10,714,600 is only the waste container and disposal cost see attachment A. * Missing is the $1,200,000 for operation and maintenance of the Silo 3 stabilization. * Missing is the $1,000,000 for operational readiness prep/procedure development. * Missing is the $1,000,000 for FDF site prep and utility integration. * Components of the 4CH00 in system $13,993,753 Therefore Silo 3 stabilization is $25,107,831 in resource loaded schedule. Silo 3 stabilization in Core of Engineering Report $22,542,040

Review of Project EM - Phase 2 Report "Fernald Environmental Management Project Critical Analysis of Operable Unit 4 Vitrification and Potential Alternatives		
Page	**Reference**	**Comment**
L-2	Table L3	Per discussion on May 1, 1997 revisit L3 to reflect the appropriate estimate sheet (see Attachment 5)
L-5		Project Management costs presented to the VE team was a summary of all level of effort activities, which include project management, facility ownership (landlord), compliance and environmental monitoring, and Parsons administrative burden.
L-6	Section: L.2	Suggest adding discussion explaining that original assumptions were changed and we're based on professional judgement. Do not disagree with assumptions, however, they are different for assumptions in the cost estimate provided to the VE team and should therefore be acknowledged.
M	Appendix M	A comparison table would be valuable in presenting this appendix. It is difficult to compare/identify the cost estimate differences as presented.

ATTACHMENT 1 774

ADA

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ADA-97-2167

DECISION ANALYSIS OF SILOS PROJECT ALTERNATIVES

FINAL REPORT

March 27, 1997

Prepared by:

APPLIED DECISION ANALYSIS, INC.

Miley (Lee) W. Merkhofer
Katherine A. Weller
Justin G. Claeys

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1.0 INTRODUCTION

Applied Decision Analysis, Inc., (ADA) was contracted by Fluor-Daniel Fernald (FDF) to help develop and apply a decision model to aid the selection of a path forward for the Silos Project. The work was conducted in coordination with the activities of the Silos Project Independent Review Team (IRT), an advisory group established to provide advice and recommendations for the decision-making process.

ADA used a formal decision analysis process to develop a model of the choice among alternative paths forward. As components of the model were developed, the assumptions and estimates were reviewed and discussed with the IRT. The exercise served to organize IRT and FDF investigations and helped ensure a comprehensive consideration of issues relevant to decision making. In addition, once the decision model was completed, it was used to provide a quantitative comparison of alternatives. These results serve as additional input to the decision-making process.

This document describes the decision model, the process by which it was developed, and the results and conclusions derived from its application.

1.2 Key Assumptions Underlying the Approach

Decision analysis is based on a strategy of decomposition, divide, and conquer. The critical components to a decision are sorted out, analyzed separately, and then synthesized at the end. Proponents of decision analysis argue that judgments are inherent in any decision. Rather than obscure underlying judgments, decision analysis makes those judgments explicit so that they can be reviewed, critiqued, and understood by others.

A key benefit of decomposition is that it allows individuals to contribute according to their specific areas of expertise. For example, a holistic approach might require an expert on one technology to express a judgment on whether her technology is superior to a technology about which she is not an expert. With decomposition, the decision model divides the comparative evaluation into its logical pieces, so that technology experts can provide inputs relevant only to the specific technologies about which they are most knowledgeable. Cost experts can provide information on costs, and risk experts can provide information on health and safety risks.

Rules of logic are used to combine the judgments input to the decision model and to determine their implications for decision making. Sensitivity analysis can be used to determine whether a different but still credible set of judgments would produce a different conclusion. A determination that different judgments produce the same conclusions often increases confidence in those conclusions. Conversely, if different judgments produce different conclusions, then the analysis has identified critical uncertainties that might be the focus of additional information-collection efforts. Regardless of the model sensitivities, the appropriate role of analysis is to serve as an aid to decision making. No model can capture all issues relevant to a decision. Decision makers must combine the analytical results with considerations outside the scope of the analysis to reach a final choice.

1.3 Participants

The participants included FDF staff, members of the IRT, stakeholders who attended IRT meetings, and decision analysis facilitators from ADA. FDF participants were organized into six technical committees:

1) Core Committee
2) Technical Issues Committee
3) Funding Committee
4) Cost and Schedule Committee
5) Regulatory and Waste-Site Availability Committee
6) Health and Safety Committee

The technical committees were formed to develop the information needed for the decision model and to provide that information to the IRT. The specific responsibilities and team leaders for each of the FDF technical committees are listed in Appendix A. The decision facilitators guided the decision analysis process, implemented the quantitative decision model, and generated the analytical results.

1.4 Steps

A fairly sophisticated decision model was required to account for complexities of the Silos Project path forward decision problem. In particular, it was necessary to account for multiple decision objectives and uncertainty over factors affecting the performance of alternatives. The steps of the decision analysis process were as follows:

1) Define objectives for the path forward.
2) Identify alternatives.
3) Establish performance measures (means for measuring the degree to which alternatives achieve objectives).
4) Identify key uncertainties that impact the performance of the alternatives and estimate probabilities.
5) Estimate the performance of each alternative under each uncertainty.
6) Aggregate the performance and probability estimates and use the results to compare and rank the alternatives.
7) Conduct sensitivity analyses.

The above steps were applied in an iterative fashion. The elements of the initial decision model were developed by the attendees of the November and December IRT meetings. The FDF technical committees were responsible for refining the decision model and providing initial estimates of all inputs needed by the model. All of the assumptions and quantitative estimates made as part of the process were presented at IRT meetings. IRT recommendations were then incorporated as revisions to the models. The initial results of the analysis were presented to the

IRT and, upon request of the IRT, additional results were generated and sensitivity analyses were conducted.

The remainder of this report presents the results of the decision analysis process and the conclusions that were drawn. Section 2 describes the decision model and the inputs. Section 3 presents the results of the quantitative analysis. Section 4 presents conclusions.

2.0 THE DECISION ANALYSIS MODEL AND INPUTS

This section describes the evolution of the decision model and summarizes the data inputs. The decision model consists of two components: (1) a value model and (2) a decision tree.

2.1 Value Model

The value model specifies decision objectives and performance measures that indicate the degree to which alternatives achieve decision objectives. It is common decision-analysis practice to organize decision objectives into a hierarchy that shows how general objectives (like "creating and maintaining a healthy environment") relate to more specific and detailed objectives (like "minimizing risk to workers") that specify how the general objectives can be achieved. The most detailed, lowest-level objectives in an objectives hierarchy serve as criteria for decision making.

A list of objectives for the Silos Project was generated by IRT members and other participants during the November and December IRT meetings. Figure 1 shows the specified objectives arranged into an objectives hierarchy. The highest-level objective is to "maximize net social benefit by creating and maintaining a healthy environment." Subobjectives relate to the levels of impacts to health and safety and to the environment, the quantities of waste requiring disposal, costs and resource investment values, stakeholder acceptance, time and schedule, the permanence of solutions, quantities of resources consumed, and learning.

To reduce the complexity of the decision model, the IRT and stakeholders selected a subset of the lowest-level objectives as a basis for defining performance measures. The selected objectives were (1) risks to workers and the public, (2) costs, and (3) schedule. These objectives were selected as decision criteria because they were judged to be (a) particularly important indicators of success and (b) likely to discriminate among the available alternatives. It was proposed that risks to workers and the public be quantified in terms of the estimated likelihoods of major accidents, the magnitudes of possible exposures, and the numbers of fatalities and injuries expected during operations. Costs were estimated in units of direct and escalated dollars. Schedule was estimated in terms of years to project completion. Figure 2 summarizes the objectives and performance measures selected for the quantitative analysis. According to the simplified logic of the model, all other things being equal, an alternative that is less costly, that is completed in a shorter schedule, or that produces lower risks is preferable.

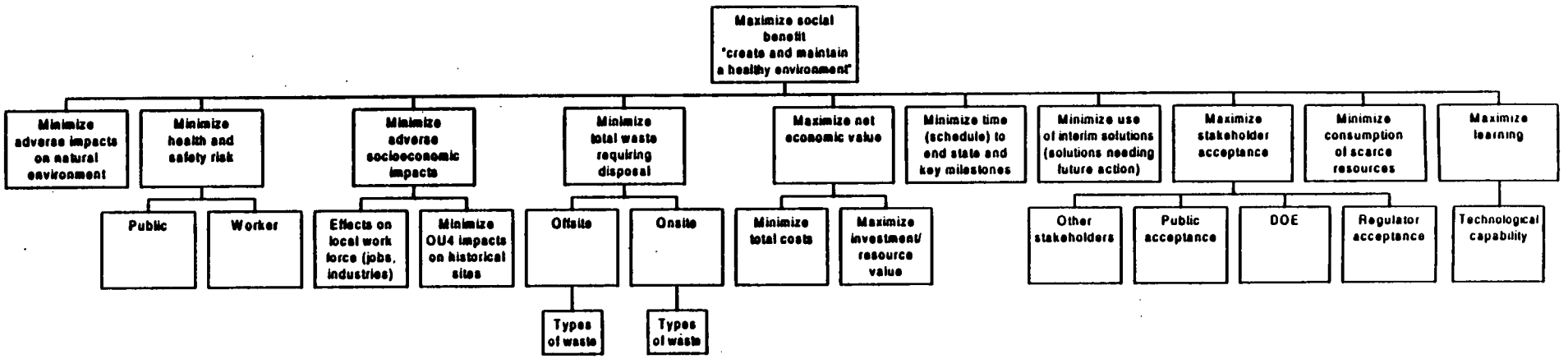

Figure 1. Initial Objectives Hierarchy

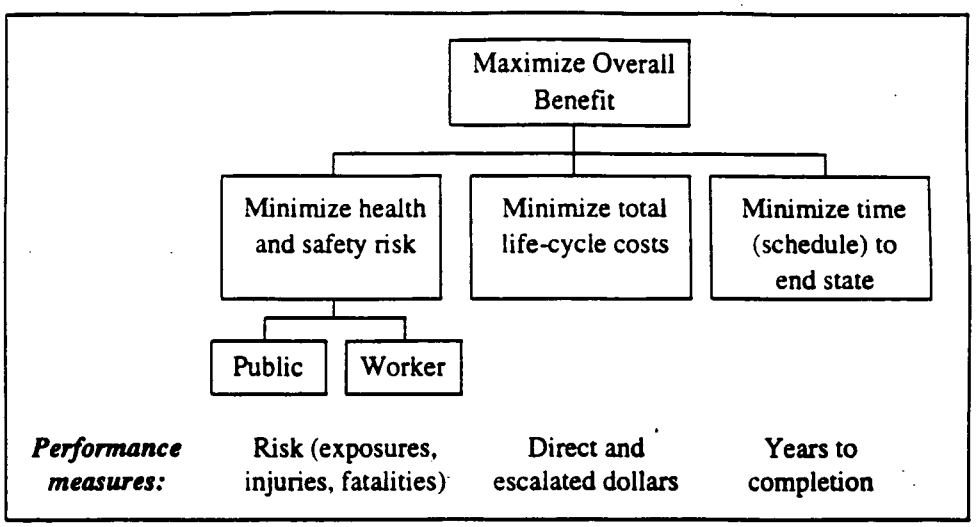

Figure 2. Objectives and Performance Measures Used in Quantitative Analysis

2.2 Decision Tree and Model Inputs

Figure 3 shows the initial version of the decision tree. A decision tree is a graphic representation that shows the alternatives that might be chosen and the key uncertainties that define possible scenarios (paths through the tree) that affect how well the selected alternative performs. A conventional analysis would estimate performance for only a most-likely or favorable set of assumptions. With a decision tree, the performance of each alternative is estimated for every path through the tree.

Three alternatives were initially considered:

Alt I: Vitrify the waste in all three silos.

Alt II: Vitrify Silos 1 and 2 and cement solidify Silo 3.

Alt III: Use stabilization in the form of some viable option for all three silos.

These options are represented by the three branches emanating from the initial node in the tree.

Five uncertainties were included in the initial tree: regulatory outcome, funding availability, technical success, availability of a waste-disposal site, and major accidents. Regulatory outcome uncertainty reflects uncertainty over whether the chosen path forward would require an ESD (explanation of significant differences), an amendment to the record of decision (ROD), or significant delays beyond that which would otherwise be expected. Funding availability reflects uncertainty over the level of funding that will be available. Technical success reflects uncertainty over whether significant technical problems will be encountered. Waste site availability reflects uncertainty over whether the Nevada Test Site (NTS) will accept the waste and the extent of delays that may occur. Major accidents uncertainty reflects uncertainty regarding the health and safety consequences and cost and schedule impacts of possible (but unlikely) accidents.

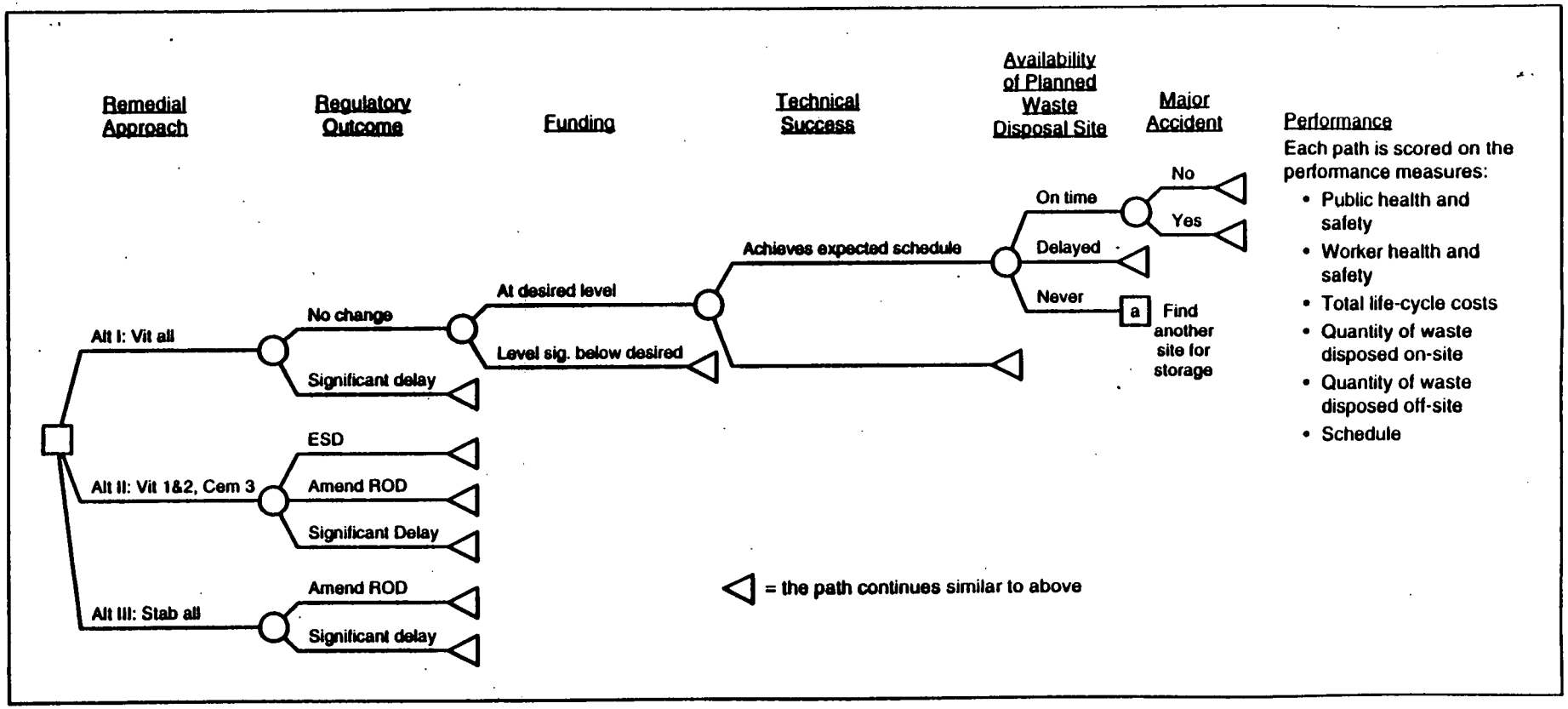

Figure 3. Initial Decision Tree

The initial decision tree was revised and refined during the succeeding meetings of the IRT. Alt I was eliminated when the IRT unanimously concluded that Silo 3 material should be immobilized by a cementation process. The regulatory outcome node was eliminated when the Regulatory and Waste Site Availability Committee concluded that the regulatory requirements were sufficiently well-defined to reasonably predict the regulatory outcomes that would occur under each alternative. Specifically, it was concluded that the "Amend ROD" possibility could be deleted for Alt II and that the "Significant delay" possibilities could be deleted for Alt II and Alt III. In essence, it was determined that the uncertain cost and schedule impacts from the regulatory process could be incorporated into the baseline cost and schedule estimates provided for each alternative. Similarly, the waste disposal site availability node was eliminated when the Regulatory and Waste Site Availability Committee concluded that, although there is some risk that the NTS will not accept processed waste from the silos, this risk is relatively small and not significantly influenced by the choice between Alt II and Alt III. Based on the elimination of these considerations from the analysis, the Regulatory and Waste Site Availability Committee was disbanded with concurrence from the IRT.

Figure 4 shows the final form of the decision tree. As illustrated, the final tree identified specific outcomes to uncertainties related to funding, technical success, and major accidents. These uncertainties are described in the subsections below. In addition, the following subsections also describe the quantitative inputs developed for the model, probability estimates for each uncertainty, and risk, cost, and schedule estimates for each of the 42 paths through the tree. Figure 5 summarizes the steps by which the various committees developed these inputs. As noted in the figure, best estimates for risk, cost, and schedule were first developed for each alternative under each of three funding scenarios. Uncertainty ranges for each cost estimate were also developed at this stage. Then, incremental cost and schedule impacts were estimated for each of the technical "problems" identified in the tree. These impacts defined "deltas" from which cost and schedule estimates were generated for each of the remaining scenarios.

2.2.1 Alternatives

Detailed descriptions of the assumptions used to define each alternative are provided in the IRT meeting minutes. Briefly, both alternatives assume a waste retrieval system based on the March '96 conceptual design, wherein Silo 1 and 2 material is removed hydraulically and Silo 3 material is retrieved pneumatically. A radon treatment system is provided for radon confinement. Support facilities include maintenance, storage, an analytical laboratory, and waste-water treatment. In both cases, Silo 3 materials would be subjected to an initial treatability study and then stabilized through cementation. Plant capacity would be 119 MT/day, with waste loading at 45% (dry weight). Treated waste would be packed in 2160 steel boxes requiring 540 truck shipments. The plant operating period would be approximately 4 months at 6 hr/day (1 hr startup, 1 hr shutdown), 5 days/wk. Waste would be in the form of a monolith. All treated waste would be shipped to the NTS by truck, and D&D wastes would be disposed of in an onsite cell.

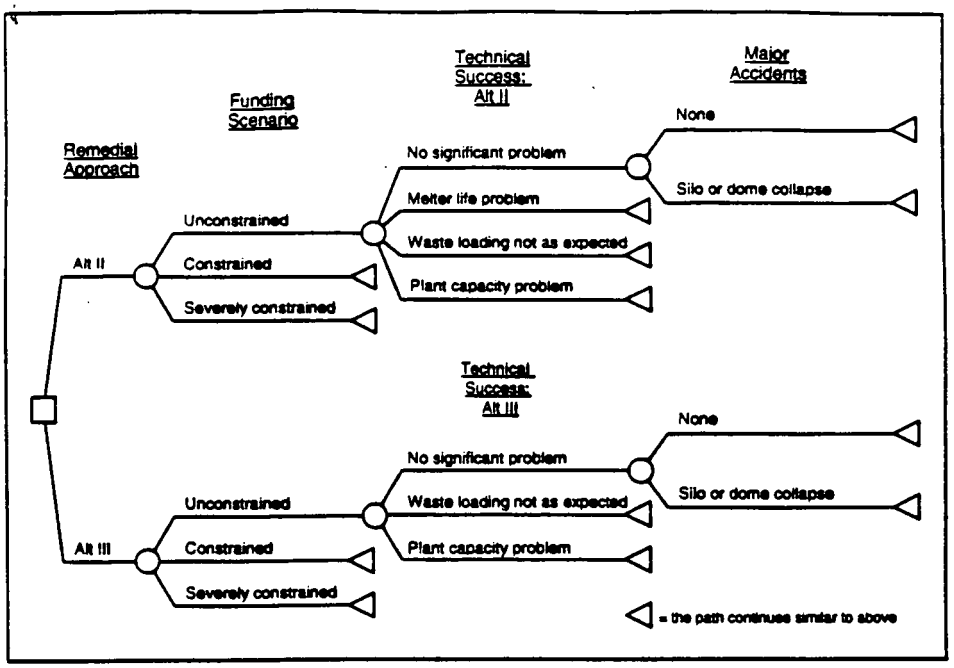

Figure 4. Final Form of the Decision Tree

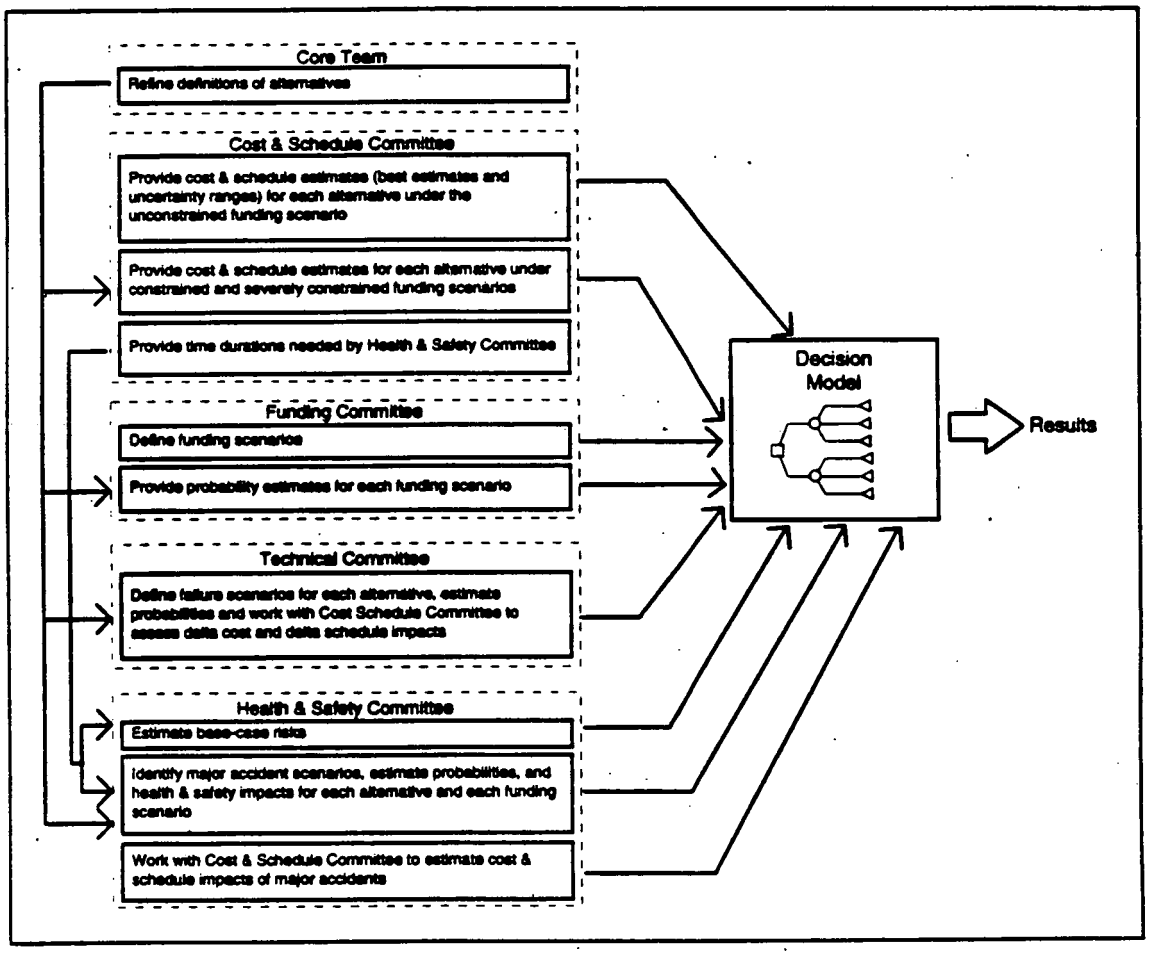

Figure 5. Committee Steps for Estimating Decision Tree Inputs

40

Alt II assumes vitrification of Silo 1 and 2 residues. Crucible testing followed by off-site mini-melter testing would use actual Silo 1 and 2 material. Pilot scale testing of surrogate material would be conducted (off-site), followed by full-scale operation. Pilot plant capacity would be 6 MT/day, with the full-scale facility operating at 12 MT/day (3 melter trains with 6MT/day melter capacities operating with one train on standby). The plant operating period would be 3 years, with 24 hr/day, 7 days/week operation. Facility availability is assumed to average 90%, with waste loading at 60% (dry weight). Waste would be in the form of glass gems with packaging in 3,800 concrete boxes requiring 1,900 truck shipments.

Alt III assumes stabilization of Silos 1 and 2 material using an approach similar to that assumed for Silo 3 material. Cement plant capacity would be 85 MT/day, with one mixer operating at 2 yds/batch with a 15 minute batch time. The plant operating period would be 3 years, with 8 hr/day, 5 days/week operation. Facility availability is assumed to average 80%, with waste loading at 20% (dry weight). Waste would be packaged in 20,700 shielded and sealed containers requiring 10,700 truck shipments.

2.2.2 Funding Scenarios

The funding branches of the tree account for the uncertainty in the available funding for the project. The Funding Committee was asked to define three funding scenarios that span the range of current uncertainty over future funding levels. The possible funding outcomes represented in the model are:

- **Unconstrained.** Annual funding is at the level desired for efficient implementation of the selected strategy.
- **Constrained.** Annual funding is $25M from 1997 through 2001, $50M from 2002 through 2005, and unconstrained thereafter.
- **Severely constrained.** Funding is at the level of the current FY97 replan.

Figure 6 shows the probabilities of these outcomes estimated by the Funding Committee. It also provides the corresponding best-judgment cost and schedule estimates provided by the Cost and Schedule Committee. As indicated, total cost and schedule are estimated to increase as the funding rate becomes more constrained. The cost and schedule estimates and the detailed assumptions on which they were based were provided to the IRT, and numerous refinements were made in the course of producing the final results shown in Figure 6. Nevertheless, it must be acknowledged that current cost and schedule estimates are extremely rough and the uncertainties in the Figure 6 estimates are large. To clarify the uncertainties involved, the Cost and Schedule Committee provided confidence ranges for their cost estimates. For Alt II, the Committee estimated that for each funding scenario that there is an 80% chance that actual costs will lie between a range that is 30% lower to 50% higher than the indicated best estimate. For Alt III, the cost uncertainty range for each funding scenario is from 50% lower to 50% higher than the indicated best estimate. Technical uncertainties, discussed below, contribute additional uncertainties to cost and schedule.

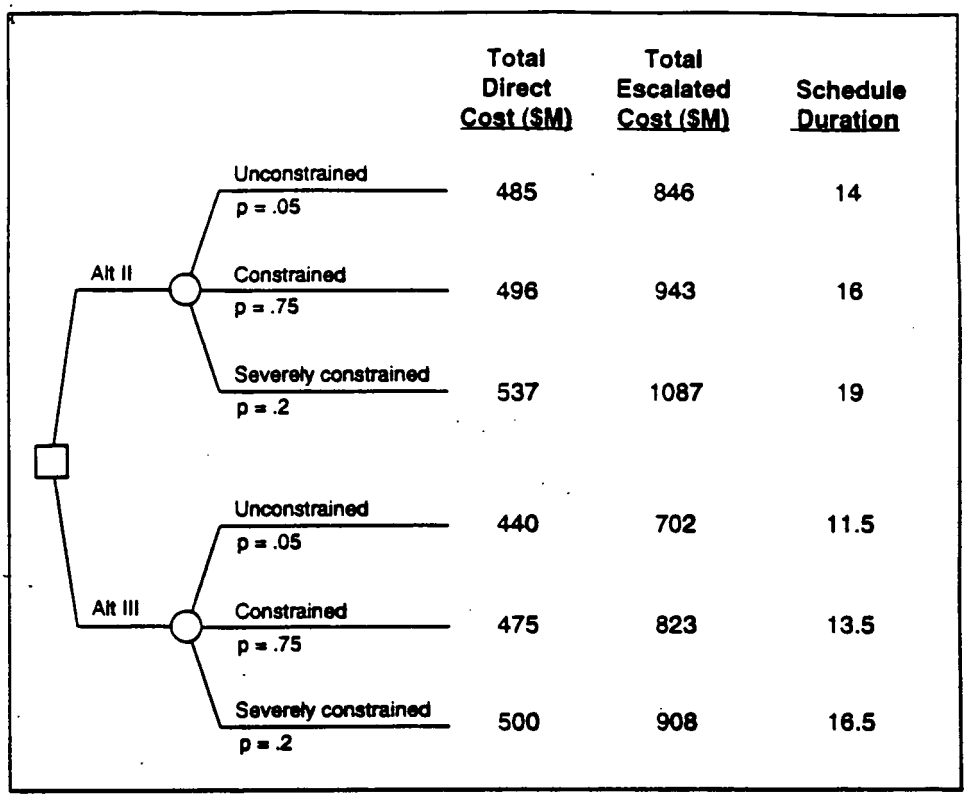

Figure 6. Cost and Schedule Estimates Under the Various Funding Scenarios

2.2.3 Technical Scenarios

The technical success branches of the tree account for unanticipated technical outcomes that may cause significant schedule or cost impacts. The technical outcomes represented in the tree were developed through a three-step process. First, a list of potential technical issues was generated and evaluated by the IRT during the January meeting. The evaluation involved a simple scoring process wherein for each issue IRT members expressed their opinions regarding (1) the likelihood of occurrence and (2) the impact given occurrence. The Technical Issues Committee subsequently expanded and refined the list and then screened it to identify the events most likely to produce significant schedule impacts or cost impacts beyond those captured in the uncertainty ranges provided by the Cost and Schedule Committee.. The technical issues represented by the branches in the tree in Figure 4 are those that remained after screening. Finally, the Technical Issues Committee estimated probabilities and worked with the Cost and Schedule Committee to develop incremental cost and schedule estimates.

As shown in the tree, the technical outcomes for Alt II are:

- **No surprises.** There are no technical problems that cause significant delays or cost increases beyond those accounted for in the base-case cost ranges.
- **Melter life problem.** Melter life does not meet design basis of 3 years. This is assumed to result in an increase in direct costs of $32M ($60M total cost) and a schedule extension of 1 year.

- **Waste loading not as expected.** Waste loading varies significantly from design basis of 60%. Two possibilities are considered:
  - **Low.** Only 40% waste loading is achieved resulting in an increase in direct costs of $86M ($148M total cost) and a schedule extension of 2 years.
  - **High.** An 80% waste loading is achieved resulting in a reduction in direct costs of $40M ($88M total cost) and a schedule reduction of 9 months.
- **Plant capacity problem.** Plant capacity does not meet design basis of 12 MT/day, resulting in an increase in direct costs of $74M ($167M total cost) and a schedule extension of 3 years.

The probabilities of these outcomes estimated by the Technical Issues Committee and reviewed by the IRT are shown in Figure 7.

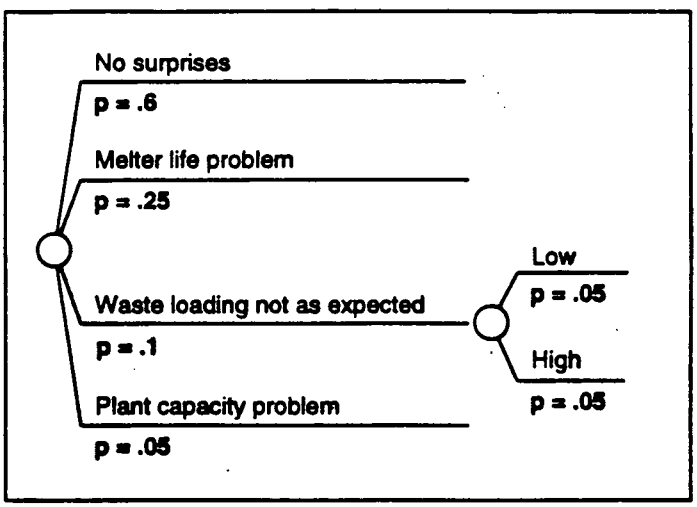

Figure 7. Alt II Technical Success Outcomes

The technical outcomes for Alt III are:

- **No surprises.** There are no technical surprises that cause significant changes in cost or schedule.
- **Waste loading not as expected.** The waste loading achieved varies significantly from the design basis of 20%. Two possibilities are considered:
  - **Low.** Only 10% waste loading is achieved resulting in an increase in direct costs of $229M ($340M total) and an increase in schedule of 3 years.
  - **High.** A 30% waste loading is achieved resulting in a reduction in direct costs of $64M ($67M total) and no change to schedule.
- **Plant capacity problem.** Plant capacity does not meet design basis of 85 MT/day, resulting in an increase in direct costs of $21M ($22M total), but no change in schedule.

The probabilities of these outcomes are shown in Figure 8.

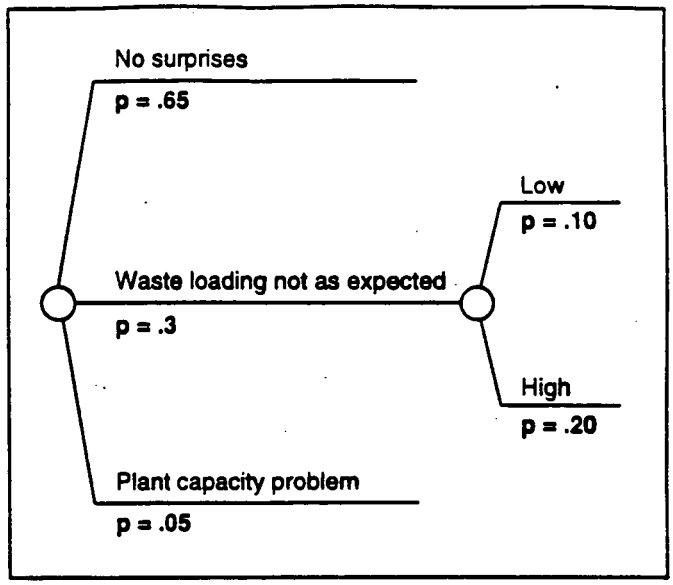

Figure 8. Alt III Technical Success Outcomes

2.2.4 Major Accident Scenarios

The major accident branches of the tree account for the possibility of an accident with a significant impact to cost, schedule, or human health and safety risk. The process for modeling major accidents was similar to that used for technical uncertainties. The Health and Safety Committee identified and then screened possible accident scenarios. To avoid being screened out, accident scenarios had to have (1) a reasonable chance of occurring and (2) if they were to occur, a significant impact on cost, schedule, or the risks to workers or the public. The only accident scenario identified by the Health and Safety Committee to meet these criteria was silo dome collapse.

The two outcomes in the model are:

- **None.** There are no accidents producing significant impacts to cost, schedule, or health & safety.
- **Silo Dome Collapse.** The dome of either Silo 1 or 2 collapses.

The Health and Safety Committee estimated exposures and health consequences to workers and to members of the public resulting from various processes and stages of the remediation process. However, in all cases analyzed, the estimated risks are relatively low and, with the exception of dome collapse, do not distinguish between the alternatives. Therefore, probability of dome collapse was the only risk measure retained for the analysis. Potential cost and schedule impacts of a silo dome collapse were not assessed and therefore are not reflected in the resulting total cost and schedule ranges. The likelihood of a dome collapse was estimated at 0.039 per year based on a previous study.

Risk estimates for disposal at the NTS were not available to distinguish between the waste forms associated with the two alternatives. However, an analysis by the Health and Safety Committee of the long-term effectiveness of the waste forms concluded that (1) radon emanation at disposal would not be an issue for either alternative, since applicable limits will be met by burial depth, (2) the cement waste form is likely to present lower risk associated with intruder scenarios, and (3) both glass and cement waste forms meet NTS waste acceptance criteria, although cement is more effective than glass with respect to lead. On this basis, it was concluded that long-term effectiveness should not represent a discriminator for the choice of a path forward.

3.0 RESULTS

The analysis consisted of generating probability distributions (also called risk profiles) describing cost and schedule uncertainties for each alternative. Probabilities of dome collapse were also computed. Cost and schedule uncertainties were obtained by aggregating the estimates of cost and schedule developed for each path through the decision tree, taking into account the uncertainty ranges and estimated probabilities for each path. The probability of dome collapse was obtained by simply multiplying the annual probability of dome collapse by the number of years until waste retrieval would be completed. This gives a slightly larger result than would be obtained using standard methods based on a constant annual probability of collapse, but the approach was viewed by the Health and Safety Committee as providing a better estimate because, among other reasons, probability of collapse may be increasing over time. Expected costs and schedules were estimated for each alternative by computing the probability-weighted averages of the estimates for each path.

Figure 9 provides a summary of the results. Note that both direct and total costs are compared. The bars indicate the uncertainties in each estimate. The expected value is indicated by the vertical line through the bar. The numbers corresponding to the left and right edges of the uncertainty bars define 80% confidence intervals. In other words, according to the estimates, there is only a 10 percent chance of incurring a value less than the left edge of the bar and a 10 percent chance of achieving a value greater than the right edge of the bar.

As Figure 9 indicates, the uncertainties in the ultimate costs and time to completion are considerable, regardless of which alternative is selected. The shapes of the underlying probability distributions for the alternatives are similar, although there are some potentially significant differences. The expected values of direct cost are $544M for Alt II and $489M for Alt III. The expected values for total cost are $1,043M for Alt II and $856M for Alt III. The expected duration is 17 years for Alt II and 14 years for Alt III. Also, it is apparent from the location of the expected values within the uncertainty bars that the skews (asymmetries in the shapes) of the underlying probability distributions are slightly different. Alt II has slightly more downside than upside potential (more chance for significantly higher costs and longer schedules), while Alt III has slightly more upside potential (more chance of lower costs and shorter schedules).

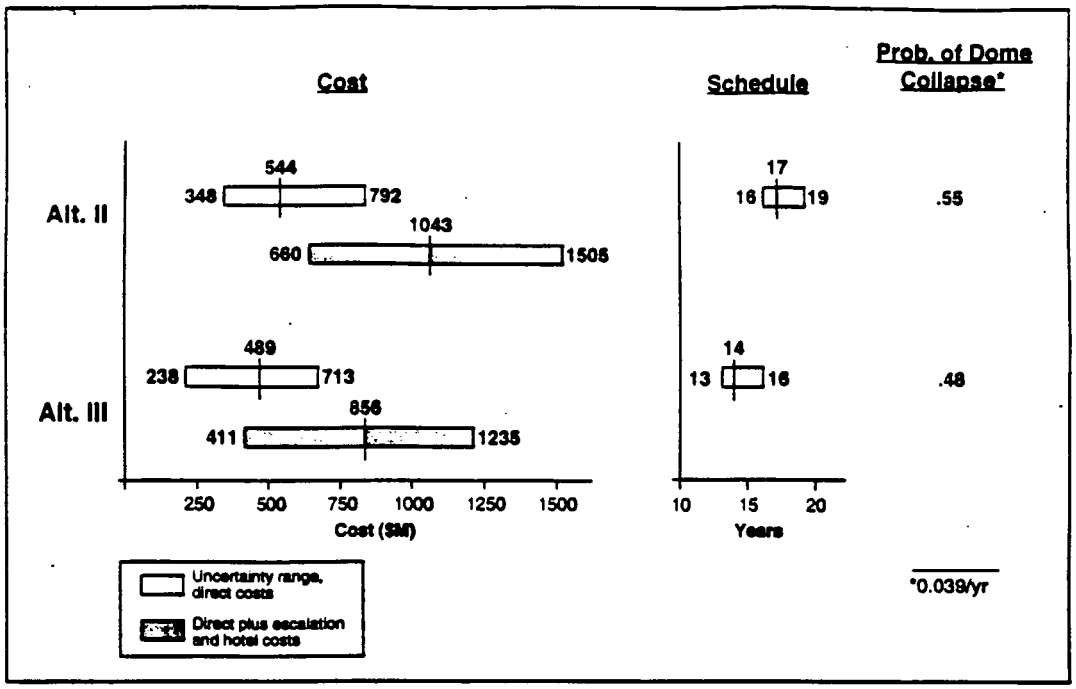

Figure 9. Summary of Estimates of Cost, Schedule, and Probability of Dome Collapse

The estimated overall probabilities of dome collapse are high, 0.55 for Alt II and 0.48 for Alt III. The high estimates for dome collapse suggest that more study is needed to resolve this issue.

Whether the estimated differences between Alt II and Alt III are sufficient to provide a basis for decision making depends on several considerations, including the sensitivity of these differences to the assumptions that were made.

3.1 Sensitivity Analysis

Sensitivity analysis was used to determine the sensitivity of the quantitative results to model assumptions and inputs. Analyses were conducted to examine assumptions related to the probability of technical success for Alt II, waste loading, monolith vs. gem waste form for Alt II, and round-the-clock operation for Alt III.

3.1.1 Probability of technical success for Alt II

The probability distribution for the costs of Alt II were recalculated assuming different probabilities of technical success. First, the probability of technical success for Alt II was increased from the nominal assumption of 0.65 to 0.85. Then, the probability of technical success for Alt II was allowed to vary within a range of 0.65 to 1. As shown in Figure 10, assuming a probability of technical success for Alt II equal to 0.85 results in an expected savings of $9M in direct costs and $16M in total escalated costs. Figure 11 shows the result when the assumed probability of technical success for Alt II varies from 0.65 to 1. As indicated, the expected direct cost for Alt III is lower than for Alt II regardless of the probability of technical success assigned to Alt II.

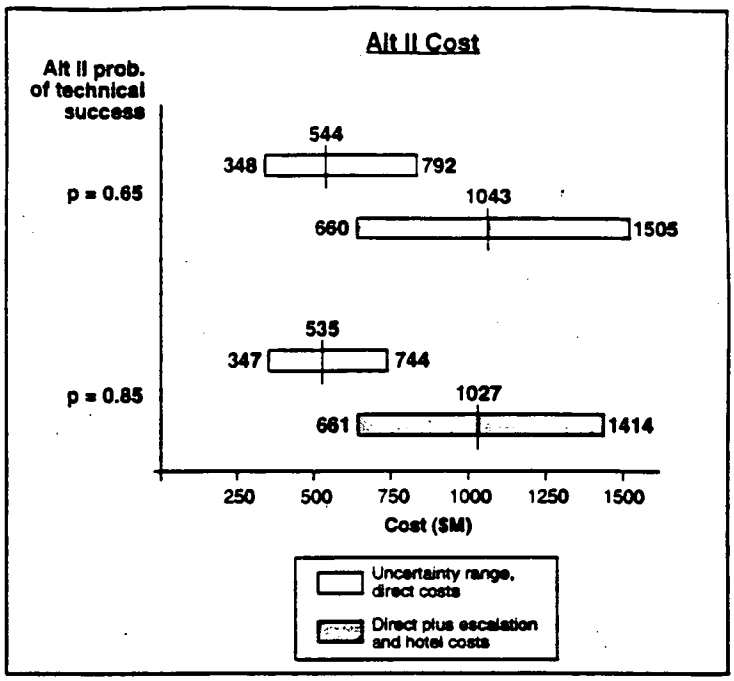

Figure 10. Sensitivity to Changing the Probability of Alt II Technical Success

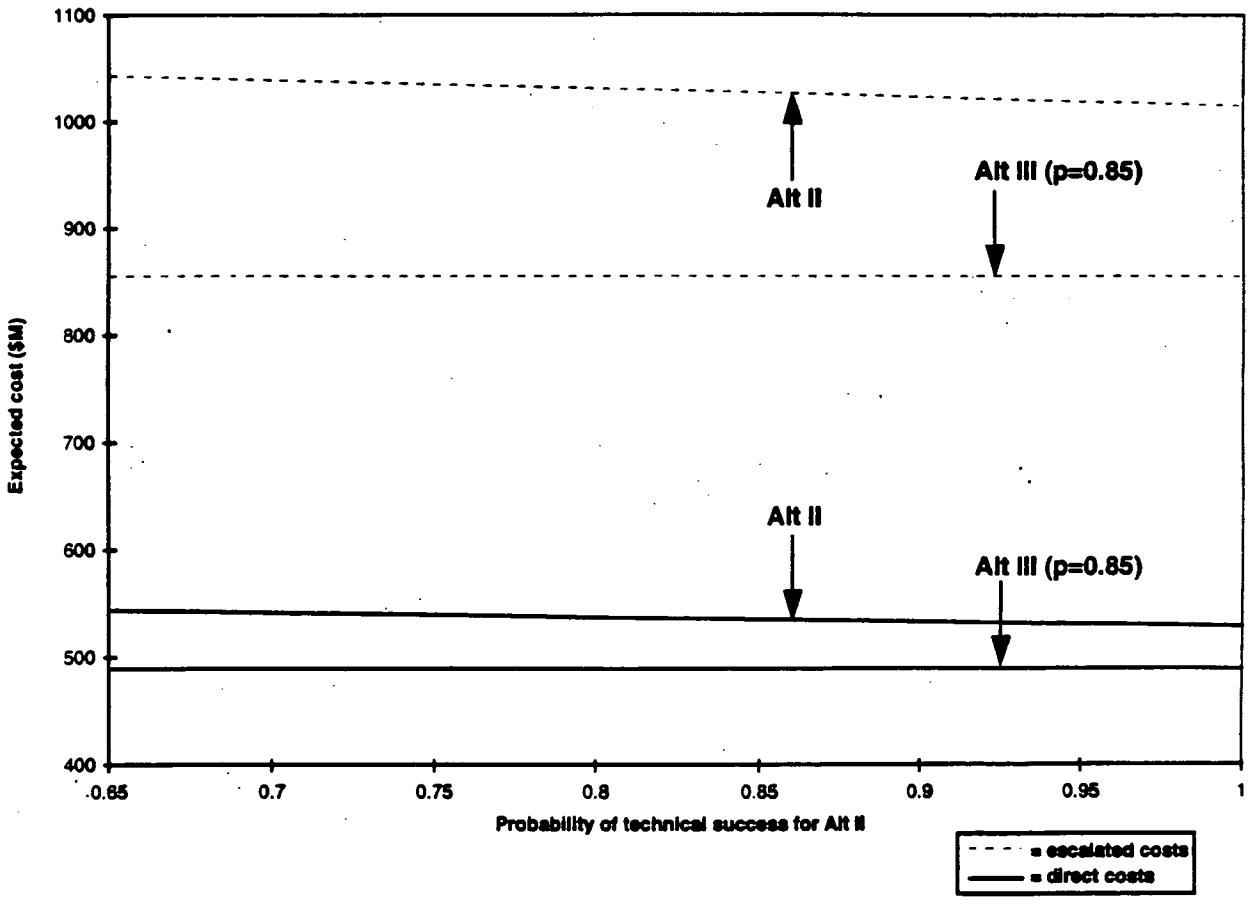

Figure 11. Sensitivity Analysis on the Probability of Alt II Technical Success

3.1.2 Waste loading

Analyses were conducted to investigate the sensitivity of costs and schedule estimates to the waste loadings assumed for Alt II and Alt III. Figures 12 and 13 show the performance of Alt II and Alt III, respectively, under the different waste-loading scenarios that are included in the decision tree. For Alt II, the possible waste-loading scenarios are 40, 60, and 80 percent. For Alt III, the waste-loading scenarios are 10, 20, and 30 percent. As the figures indicate, cost and schedule estimates are quite sensitive to waste loading assumptions.

3.1.3 Monolith vs. gem waste form for Alt. II

The costs for Alt II were reestimated assuming a monolith waste form instead of gems (changing the waste form was estimated to produce no significant impact to schedule). With a monolith waste form, the 70% packing factor assumed with gems was increased to 80%. This change would save 1/8 of the estimated $80M direct shipping costs, or $10M. With escalation, this translates into roughly a $16M savings in total costs. Although not addressed in this sensitivity analysis, there may be other cost impacts of shifting to a monolith waste form, such as savings resulting from reduced system complexity or cost increases caused by higher waste-sampling costs or the greater difficulty of dealing with off-spec material.

3.1.4 Round-the-clock operation for Alt III

The costs and schedule for Alt III were reestimated under an assumption that the cement plant would be operated 24 hrs/day. Round-the-clock operation would allow a schedule savings of up to 2 years, but would require a shift to rail transport to avoid excessive truck traffic. Rail transport was estimated to add approximately $250/container in shipping costs, for a total of $5M, plus a $3M increase for running 3 shifts. However, there is a direct cost decrease associated with saving 2 years of engineering project management at roughly $7M/yr, or $14M. This results in a net direct cost savings of $6M, which translates to a total escalated cost savings of $11M. Finally, there is an additional escalated cost savings of 13% of $63M D&D costs (because these costs would be incurred two years sooner), plus 2 years of hotel costs, at $26M/year. This adds another $60M in escalated cost savings, for a total estimated escalated cost savings of $71M.

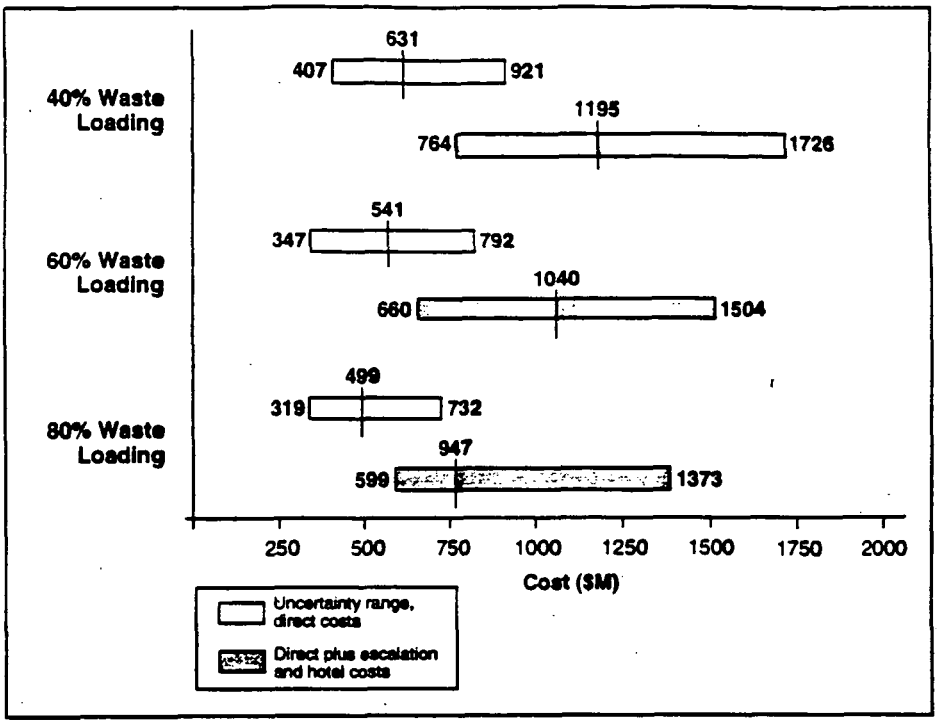

Figure 12. Sensitivity Analysis on Alt II Waste Loading

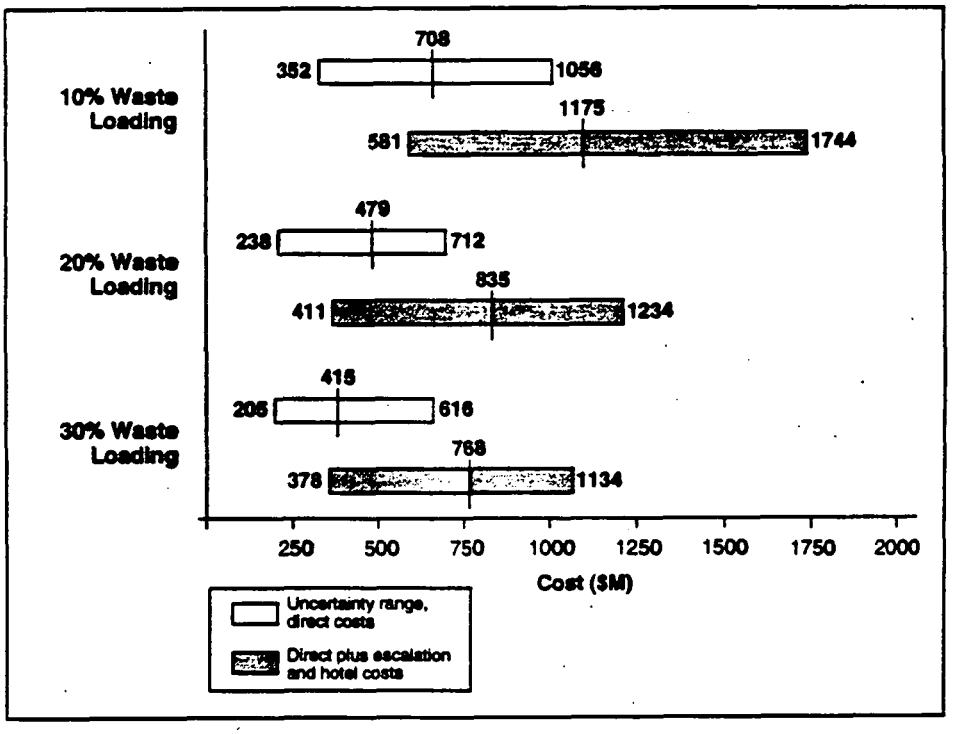

Figure 13. Sensitivity Analysis on Alt III Waste Loading

3.2 Value Of Information

It is sometimes cost-effective to collect additional information prior to making a decision. This is the case if the costs of collecting the information (the costs of acquiring the information plus the costs of delay) are less than the value of the information that is collected. The value of the information is the expected savings that would result based on the ability to alter the choice depending on what is learned.

Decision analysis techniques allow the value of information about uncertainties in a decision model to be calculated. The easiest calculation is the value of perfect information, an estimate of what it would be worth to completely resolve each of the uncertainties represented in the decision tree. In the tree, changing the decision sequence so that an uncertainty occurs before the decision is equivalent to having perfect information about that uncertainty. The savings produced by this reordering is the value of perfect information about the uncertainty that has been moved to the front of the tree. Thus, the value of resolving individual uncertainties can be easily obtained by altering the structure of the decision tree.

The value of perfect information provides guidance for information-collection activities. For example, if the value of information about a particular uncertainty is very high, then the feasibility of collecting information related to that uncertainty can be determined. The estimated costs can then be compared with the value of information to determine whether it may be cost-effective to focus information collection activities in that area. Conversely, if the value of information about a particular uncertainty is zero or low, then it may not be cost-effective to consider information-collection activities directed at these uncertainties.

Figure 14 summarizes the values of perfect information (in direct dollars) for the various uncertainties included in the model.

Uncertain Factor	Alt II	Alt III	Both Alt II & III
Melter Life	~0	N/A	N/A
Waste Loading	~0	$16M	$16M
Plant Capacity	~0	~0	~0
All Tech Success Factors	~0	$16M	$16M
Cost Estimates	$32M	$47M	$66M
All Tech & Cost Estimates	$32M	$55M	$73M

Figure 14. Value of Information

As indicated, it is generally less valuable to collect additional information relevant to Alt II compared to Alt III. This is due, in part, to the shapes of the probability distributions. As indicated previously, the probabilities suggest that additional information about Alt II is more likely to indicate that the alternative performs less well than expected, with the reverse being true for Alt III. Nevertheless, the values of information in several areas are quite large, suggesting that consideration be given to delaying a final commitment for the purpose of obtaining better information. In particular, the higher values of information about Alt III suggest that a strategy that preserves both options while resolving key uncertainties related to waste loading and other cost factors for Alt III may be worth consideration.

3.4 Summary

The analysis shows the logical implications of judgments provided by the FDF technical committees and reviewed by the IRT. The key results of the analysis are summarized below:

- The analysis concluded that either alternative is capable of technical success. The Technical Issues Committee could identify no technical problems that might be encountered under either alternative that could not be overcome by additional time and money. Nevertheless, the analysis shows that there is considerable potential for technical and other difficulties to increase cost and schedule.

- Although the uncertainties are considerable, the quantitative results favor Alt III. Alt III is expected:

  - to be less costly, roughly $55M less in direct costs, $190M counting escalation and hotel costs.

  - to be completed approximately 3 years sooner.

  With round-the-clock operation of the cement plant the gap between Alt II and Alt III is estimated to increase to roughly $60M in direct costs and $260M in total costs. The expected schedule difference increases to 5 years.

- The fact that the probability distributions overlap (indicating, for example, that Alt II could turn out to be less expensive than Alt III) does not necessarily negate the importance of the estimated differences. According to decision theory, a choice that has a more favorable expected cost and schedule and that has the same or lower total uncertainty should be preferred, other things being equal. When probability distributions similar to those obtained here are encountered in applications in the world of commercial R&D, they are generally regarded as sufficient for decision making.

- Unlike commercial R&D, additional considerations are relevant to the question of whether the distinctions in cost and schedule (and the probability of dome collapse) are significant in this context. Of considerable relevance is the degree of credibility that external parties (including the IRT) assign to the assumptions and estimations underlying this analysis. Sensitivity analyses indicate that the conclusion is robust that Alt III is likely to produce lower costs and a quicker schedule—changing any individual assumption within a plausible range will not alter the conclusion. On the other hand, the IRT was not, in most cases, the primary source of the assumptions and inputs for this analysis. The IRT reviewed the

assumptions and sometimes made changes, but did not accept responsibility for, or ownership of, those assumptions. Thus, while the analysis reflects the best-professional estimates of members of the FDF technical committees, this cannot be said to necessarily be the case for the IRT. Thus, external parties will naturally have less confidence in the analytical conclusions that those who participated more directly in the analysis.

- Another important difference between this context and commercial R&D is that in this case there are important considerations beyond cost and schedule. Some of these considerations that are not included in the quantitative analysis appear in the more complete objectives hierarchy in Figure 1. If any party were to conclude that Alt II is preferable to Alt III on some dimension other than cost, schedule, or risk (e.g., on public acceptance) and that this difference was more significant or important than the differences estimated for cost and schedule, then it would be logical to deviate from the conclusions of the quantitative analysis.

- Although not analyzed, an alternative of parallel development may be superior to either Alt II or Alt III. Value-of-information results suggest that there is high value to retaining both options while collecting additional information. There may be value to using the decision framework described in this report to evaluate one or more parallel development alternatives. Questions that could be addressed through such an analysis include: Is retaining an option to revert to cementation worth the costs? How can information-collection activities be optimized to support a final choice? What is the decision rule for deciding whether and when to abandon or revert to a cementation option?

- The analysis indicates that dome collapse prior to waste retrieval may be a serious risk. This may be an artifact of an overly-conservative risk analysis, or it may be a legitimate concern. More analysis of this issue is needed.

4.0 CONCLUSIONS

The analysis provided an integrated, comparative evaluation that incorporated the best technical judgments of FDF technical committees as reviewed and refined by the IRT. The analysis addressed, among other factors, current concepts for implementing each option; impacts of funding uncertainties; legal and administrative ramifications; technical uncertainties; total waste volumes; treatment, storage and transportation risks and risks of major accidents; and costs and schedule. The analysis showed that the best-technical judgments provided by the FDF technical committees and reviewed by the IRT logically imply that Alt III is likely to be superior to Alt II with regard to cost and schedule and unlikely to be signficiantly different with regard to health and safety risk. However, the analysis also suggests that the uncertainties are sufficiently great that serious consideration should be given to evaluating a parallel development option.

Although the analysis identified and quantified distinctions between the alternatives, those differences were not sufficiently compelling to promote a consensus among IRT participants. IRT members split their recommendations, with a majority of members recommending Alt II and a minority recommending Alt III. Despite the IRT review of model inputs and the general insensitivity of model results to moderate changes in assumptions, a

majority of IRT members did not feel that the quantitative cost and schedule inputs have sufficient credibility to motivate recommending a signficant change for the path forward.

Despite the differences between IRT recommendations and the decision model quantitative results, the analysis is viewed as having provided important contributions for the decision-making process:

1) It facilitated the IRT conclusion that there are no insurmountable barriers to technical success for either alternative. At the same time, the analysis showed that technical uncertainties contribute significantly to cost/schedule uncertainties.
2) It produced realistic estimates of the current uncertainties in cost/schedule. It demonstrated that uncertainties are large and unlikely to be resolved soon. As such, the analysis helps to promote reasonable expectations by external parties.
3) It identified the technical process uncertainties most critical to success.
4) It identified issues of potential concern that deserve further analysis (e.g. dome collapse).
5) It forced identification and analysis of potential barriers for the path forward (e.g. regulatory, waste acceptance criteria, availability of a waste disposal site).
6) It provided a means for analyzing potential improvements (e.g. waste loading for vitrification and cementation, round-the-clock operation of a stabilization facility).
7) It generated insights (e.g. that schedule impacts produce large changes to total escalated costs, that parallel development of vitrification and cementation has high value).
8) It enabled issues to be exposed and clarified through sensitivity analysis (e.g. monolith waste form).
9) It clarified the magnitude of health and safety risks and provided confidence that regulatory requirements can be met.
10) It provided a structured framework for organizing discussion, identifying and analyzing issues, and providing information for consideration by the IRT.

APPENDIX A

Committee Responsibilities and Tasks Lists

Core Team Responsibilities

1) Develop initial summary description for each alternative. Pass out to all committees to verify consistency with their assumptions.
2) Revise summary definitions/assumptions for each alternative based on Jan IRT meeting.
3) Keep other committees up to date on current assumptions lists.
4) Update and distribute lists of committee responsibilities and ensure that tasks are being completed.
5) Develop and distribute schedule for completion of committee tasks.

Cost and Schedule Committee Responsibilities

1) Review information and understanding relevant to assessing cost and schedule.
2) For each alternative, estimate "base-case" life-cycle cost (by year) and schedule. Provide a best estimate and uncertainty range (10th percentile, 90th percentile).
3) Review revised descriptions of alternatives and verify that assumptions are consistent with those used to estimate cost and schedule or modify cost and schedule estimates as needed. List additional specific assumptions used for the cost and schedule estimates.
4) Work with Technical Committee to determine extent to which technical risk scenarios developed by IRT at Jan 22 meeting are already captured within cost and schedule uncertainty ranges.
5) Determine which of the health and safety, regulatory, and programmatic uncertainties identified by IRT at Jan 23 meeting are already captured within cost and schedule uncertainty ranges. Extend cost and safety ranges as necessary to accomodate any regulatory or programmatic uncertainties that have not previously been captured. Refer remaining health and safety uncertainties to the Health and Safety Committee.
6) Estimate cost and schedule (best estimates and uncertainty ranges for cost, for sure, for schedule if possible) for each alternative for the constrained and severely constrained funding scenarios. Uncertainty ranges should approximate 10 and 90 percentiles of cumulative distributions. Work with Technical Success Committee and Health and Safety Committee to develop delta cost and schedule esimates (and time periods during which delta cost and delta schedule occur) under each technical risk scenarios and major accident scenario.
7) For each alternative and each funding scenario, provide Health and Safety Committee with time durations for computing total risk, including durations for retrieval packaging and shipping, disposal and D&D.

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Funding Committee Responsibilities

1) Review information and understanding relevant to assessing funding.
2) Define possible funding scenarios (i.e., unconstrained, constrained, severely constrained).
3) Review descriptions of alternatives and verify consistency with Funding Committee assumptions.
4) Estimate probability of each funding scenario under each possible regulatory outcome. List any specific assumptions, beyond the descriptions of the alternatives, used for the estimates.

Technical Issues Committee Responsibilities

1) Review information and understanding relevant to assessing likelihood of technical success.
2) Define parameters of technical success.
3) Understand all relevant factors impacting technical success.
4) Review revised descriptions of alternatives and verify consistency with Technical Committee assumptions.
5) Review each of the eight technical risk scenarios identified and evaluated at the Jan 22 IRT meeting. Combine like scenarios. Clarify scenario definitions by specifying the "success assumption" and the "extreme assumption" for each uncertainty. Determine which scenarios are already captured in baseline cost and schedule uncertainty bounds. Decide which, if any, should instead be represented as explicit scenarios in the decision tree. Develop delta cost and delta schedule for each scenario to be represented in decision tree. Assess probability (using IRT weighted average probabilities, to be provided by ADA, as guidance). List any additional specific assumptions, beyond the descriptions of the alternatives, used for the estimates.
6) Verify delta cost and delta schedule estimates are consistent with assumptions used by Cost and Schedule Committee.

Health and Safety Committee Responsibilities

1) Review information and understanding relevant to assessing public and worker health and safety risks.
2) Identify types of risks that need to be assessed (e.g., remediation, packaging and shipment, disposal, D&D) and establish measures to be used to quantify each. Review any suggestions from Jan 23 IRT meeting regarding additional risk scenarios that should be addressed. Determine response for each IRT suggestion.
3) Review descriptions of alternatives and verify consistency with Health and Safety Committee assumptions.
4) For each type of risk to be included, and each alternative, make quantitative estimates of "base-case" risks. List any specific assumptions made in the estimations.
5) Identify potential (low probability/high consequence) major accident scenarios and screen them based on probability of occurrence and magnitude of the health and safety impact.
6) Assess consequences and probabilities of each risk scenario that remains after screening. List any specific assumptions, beyond the descriptions of the alternatives, used for the estimates.
7) Work with Cost and Schedule Committee to estimate impacts of major accidents on cost and schedule.

Regulatory and Waste-Site Availability Committee Responsibilities

1) Review information and understanding relevant to assessing regulatory impacts and waste-site availability.
2) For each alternative, define the possible regulatory outcomes (e.g., no change, ESD, amend ROD). Identify issues impacting the regulatory outcome.
3) Verify that delays in NTS availability would not affect the overall schedule. Verify that the likelihood of NTS unavailability is not dependent on the alternative selected or regulatory outcome.
4) Review descriptions of alternatives and verify consistency with Regulatory and Waste-Site Committee assumptions.
5) Verify that potential delays in the regulatory process and NTS availability are accommodated within the overall cost and schedule and uncertainty estimates.
6) Estimate probability of each possible regulatory outcome. List any specific assumptions, beyond the descriptions of the alternatives, used for the estimates.

John Smets

ATTACHMENT 2

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Structural Evaluation of Silos 1, 2, 3, and 4 With 6-Foot Diameter Opening at Center Based on 1986 NDT Test Results

Operable Unit 4
Project Order 92
September 1993
Revision 0

Environmental Remedial Action Project
Fernald Environmental Management Project
Fernald, Ohio
FERMCO Subcontract No. 2-21487

PARSONS

Fairfield Executive Center
6120 South Gilmore Road
Fairfield, Ohio 45014

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Structural Evaluation of Silos 1, 2, 3, and 4 with 6-Foot Diameter Opening at Center Based on 1986 NDT Test Results

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LIST OF ACRONYMS AND ABBREVIATIONS

CDR	Conceptual Design Report
DOE	United States Department of Energy
FEMP	Fernald Environmental Management Project
LC	Loading Combination
NDT	Non-Destructive Test
OU	Operable Unit
PC	Personal Computer
psf	pounds per square foot
psi	pounds per square inch

SECTION 1

INTRODUCTION

1.1 Background Information

The Fernald Environmental Management Project (FEMP) established operations in 1951 under orders of the Atomic Energy Commission and produced uranium and other metals for use at other United States Department of Energy (DOE) facilities. The FEMP is located near Fernald, Ohio, approximately 20 miles northwest of Cincinnati. At present, production at the FEMP has ceased and the environmental remediation of the entire site is ongoing. To aid in the remediation effort, the FEMP is separated into Operable Units (OUs) 1, 2, 3, 4, and 5.

Silos 1, 2, 3, and 4 are located in the west central boundary of the FEMP in OU-4. Silos 1 and 2, also known as the K-65 Silos, contain radium-bearing residues from pitchblende (high-grade uranium/radium) ore processes at the FEMP, the Lake Ontario Ordnance Works (currently known as the Niagara Falls Storage Facility), and the Mallinckrodt Chemical Works.

Silo 3 contains dry uranium oxide and other metal oxides generated at the FEMP refinery operations.

Silo 4 has never been used and is empty.

1.2 Silo Construction, Tests, and Modifications

Silos 1, 2, 3, and 4 were originally designed by Preload Engineering, Inc., and were constructed by Catalytic Construction Company during 1951-1952. The silos have an approximate 80-foot inside diameter, 27-foot height at the top of the wall, and 36-foot height to the top of the dome at the center of the silo. The walls were originally designed to be 8 inches thick and cast in place with 4,500 pounds per square inch (psi) concrete. They are wrapped on the outside surface with prestressed steel wires and covered with 1-inch-thick gunite. The walls have no vertical reinforcement or steel diaphragm. The wall reinforcement was primarily provided by vertical preload units spaced 4 feet apart around the circumference. The dome was originally designed to be 8 inches thick maximum near the edge, tapering to 4 inches thick minimum at the center, and was cast in place using 4,500 psi concrete. Dome reinforcement consisted primarily of welded wire mesh as shown in the engineering drawings (Preload a-f).

Over the years the silos have shown visible signs of deterioration and have undergone periodic rep In 1963, the silo walls were given a waterproof coating. In 1964, soil berms were built around ar the top of the walls for Silos 1 and 2 at a slope of 1.5:1, and were enlarged to a slope of 3:1 in 1 In 1986, a 30-foot diameter protective cover constructed of steel and plywood was added to the dc of Silos 1 and 2. In 1987, 3 inches of rigid polyurethane foam topped by a 45-mil membrane was pl on top of the Silo 1 and 2 domes.

1.3 Project Authorization

Under the scope of work and as one of the items of work for Project Order 92 (PO-92), Revision 0, d April 2, 1993, Fernald Environmental Restoration Management Corporation (FERMCO) has author PARSONS to perform finite element analyses to determine the structural integrity of the silo walls domes by using the NDT results obtained by Camargo and Associates in 1986.

Under the scope of work for a separate Project Order (PO-76), FERMCO has further author PARSONS to re-evaluate and confirm the findings of this report using the results of the new NDT. new tests are scheduled to be started in September 1993 and completed by the end of October 1993

SECTION 2

OBJECTIVE

The objective of this report is to perform an independent structural analysis to determine the structural integrity of Silos 1, 2, 3, and 4 based on the following criteria:

1) Silo material properties and data from 1986 NDT results by Camargo and Associates (Muenow & Associates 1985a, b).

2) Design criteria and loadings per DOE Order 6430.1A (DOE 1989), a low-hazard facility category (Ref. 4), Project Order Plan PO-92 (PARSONS 1993b), and Design Criteria Package for PO-92 (PARSONS 1993a).

3) A proposed 6-foot-diameter opening at the center of the dome (PARSONS 1993b).

SECTION 3

PREVIOUS STUDIES

The silos have been a subject of study due to past records of leakage and public concern about their serviceability (FERMCO 1993). Only a brief summary of the previous studies made on the silos is presented here.

In 1986 Camargo and Associates performed static analyses of Silos 1, 2, 3, and 4 (Camargo 1986a, b). The study included static analyses based on field data obtained by NDTs on Silos 1, 2, 3, and 4. Silos 1 and 2 have been studied more extensively than Silos 3 and 4.

In 1989 Camargo and Associates performed additional dynamic analyses on Silos 1 and 2 to include the effect of the added cover and addition of 4 feet of an internal sand layer (Camargo 1989).

In 1990 Bechtel National Inc. performed analyses on Silos 1 and 2 based on core test results obtained from the empty Silo 4 (Bechtel 1990).

In 1990 the University of Cincinnati (1990) made a probabilistic risk assessment for Silos 1 and 2. In April 1991 Sandia National Lab (SANDIA 1991) made a study of the analyses by Bechtel and Camargo.

In November 1991 PARSONS completed a review of all the reports and analyses to date on Silos 1 and 2 as a part of the Safety Analysis Report (SAR) for Silos 1 and 2 (PARSONS 1991).

The scopes of previous studies were varied in nature. Accordingly, the findings and conclusions were different. Some modifications were made to Silos 1 and 2 domes based on these studies.

Following is a brief summary of some of the previous findings and recommendations:

1) "The condition of each of the silo domes (Silos 1 and 2) must be considered structurally defective, with no definable life expectancy" (Bechtel 1990).

2) "The contents of the silos (Silos 1 and 2) and earthen embankments around the silos must be removed simultaneously to avoid damage and collapse of the silo walls and/or slab" (Camargo 1986b).

3) "The two K-65 silos, as analyzed for this report, are capable of sustaining the pr static loads plus the internal radon attenuation sand layer" (Camargo 1989).

4) "It is suspected that likelihood of seismically induced failure of the silos is significa Sandia Labs (SANDIA 1991).

5) "Domes for both silos (Silos 3 and 4) are in good condition and should remain s some time. Domes are capable of supporting 100 pounds per square foot live load. The walls of both silos are in good condition, but there are a few areas of deteriora Most of the deterioration is occurring in the post-tensioning wires. Silo 4 which is e has undergone more deterioration than Silo 3. This deterioration has occurred in that have through cracks in the wall allowing moisture to corrode wires" (Cam 1986b).

It must be emphasized that the above summary is incomplete and the original reports must be st before drawing any conclusions.

SECTION 4

STRUCTURAL ANALYSIS

4.1 Method of Analysis for Silos 1, 2, 3, and 4

The analysis was based on elastic behavior for determining the internal forces and displacements of thin shells (ACI, ACI 1988, McGraw Hill 1965) and assumptions stated in Subsection 4.2. The allowable stress design method as permitted by ACI 318 was used for evaluating the stresses in the silos.

SAP90, a PC-based general purpose finite element analysis computer software, was used for the analysis of Silos 1, 2, 3, and 4. SAP90 was developed by the author of the original mainframe SAP series of programs and is a reputed and widely used computer program in the field of structural analysis. The SAPIN graphics model generator was also used in creating the model. The input data was reviewed for correctness using the SAPLOT graphics processor before the final runs were made.

A quarter model was used for the finite element model with appropriate boundary conditions. Typical details applicable for all silos modeled use a fine mesh to include the 20-inch-diameter manway and 24-inch-diameter hatch.

The wall was assumed hinged at the base and fixed at the dome wall intersection.

A separate finite element model was developed for each silo to include its own test result on concrete thicknesses, wire data, and concrete strengths. Figures 4-1 and 4-2 show typical finite element models for Silos 1, 2, 3, and 4. Figures 4-3, 4-4, 4-5, and 4-6 show the details of the model at the openings. Additional details of the model are included in a separate calculation package for each silo.

4.1.1 Description of Finite Elements

Three-dimensional shell elements combining the membrane and plate behavior were used. The plate-bending behavior includes two-way, out-of-plane plate rotational stiffness components in a direction normal to the plane of the element.

The plate-bending behavior does not include any effects of shear deformation.

The membrane behavior includes translational in-plane stiffness components in the direction normal to the plane of the element.

The element stresses were evaluated at eight integration points and extrapolated to the joints o element.

Triangular elements were used only as transitional elements since their stress recovery is poor.

To get meaningful stress contours, all the elements were generated so that the local axes were in the s direction as much as possible. Figure 4-7 shows a typical detail of the element local axes near the d wall intersection.

Figure 4-7 also shows fictitious zero stiffness, zero mass beam elements used to input the radial pres loads at the beam element end joints only. This technique was used to overcome the limitation of j load specifications for interior joints.

4.2 Assumptions

The following assumptions were made in this analysis:

1) The silos were built to the same dimensions as shown on the referenced drawings (Preload :

2) The results obtained by a quarter model with proper boundary conditions are representativ the results for a full model.

3) Construction loads are not included in the dome roof live load of 20 pounds per square foot (p

4) The analysis was based on uncracked concrete structure and the material was assumed line elastic, homogeneous, and isotropic. Poisson's ratio was taken as zero.

5) The cracks recorded (Muenow and Associates 1985a, b) and observed on walls and dome Silos 1, 2, 3, and 4 were surface cracks only and not structural cracks.

6) The material and property data for concrete and prestress wire were the same as obtained by 1 NDT results for Silos 1, 2, 3, and 4 (Muenow & Associates 1985a, b).

7) The prestress wire conformed to ASTM A821 and has not been damaged other than percentage wire loss reported (Muenow & Associates 1985a, b).

8) The yield strength for reinforcement and welded wire mesh was taken as 40,000 psi.

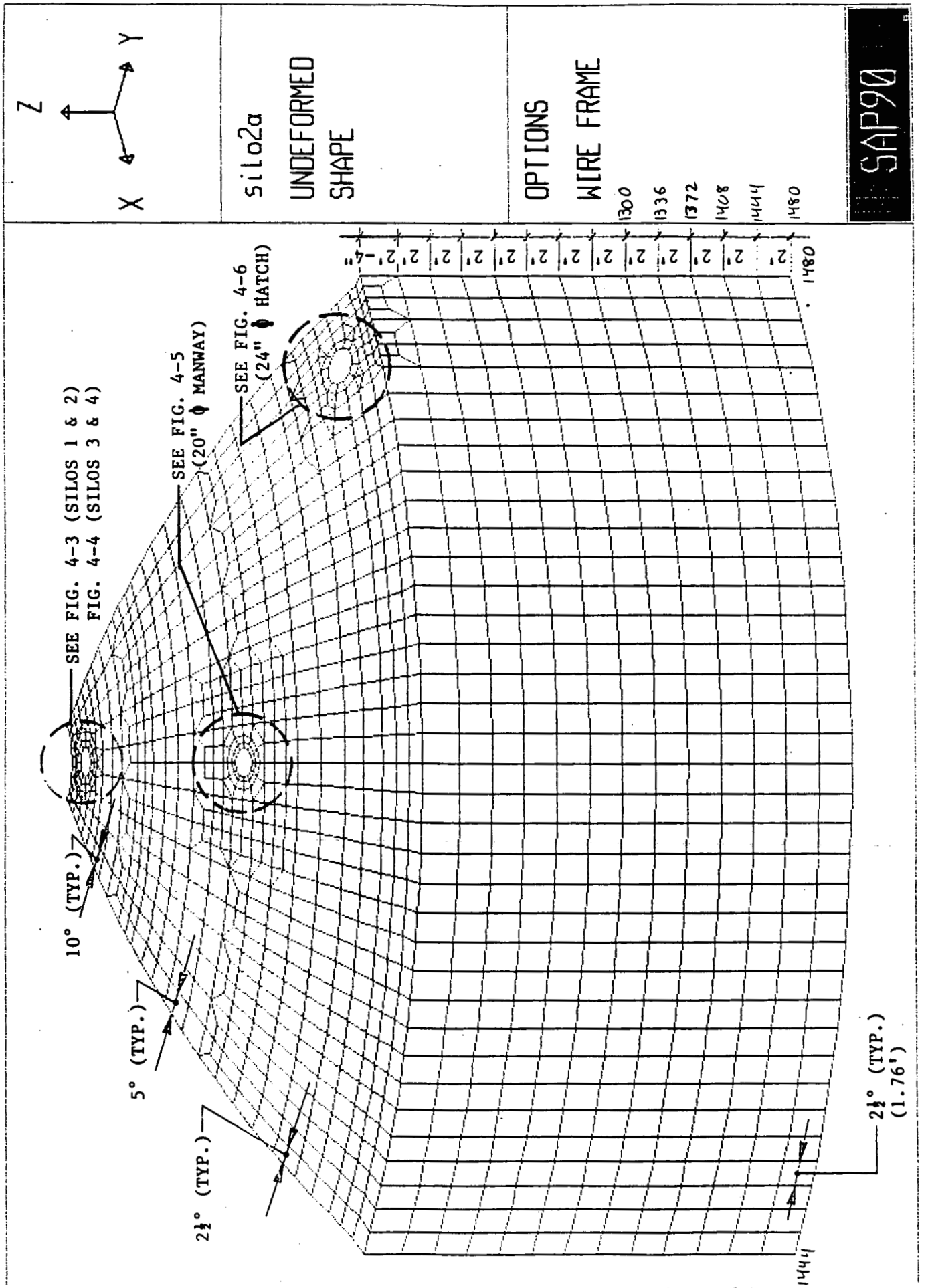


Figure 4-1 - Typical Finite Element Model for Silos 1, 2, 3, and 4

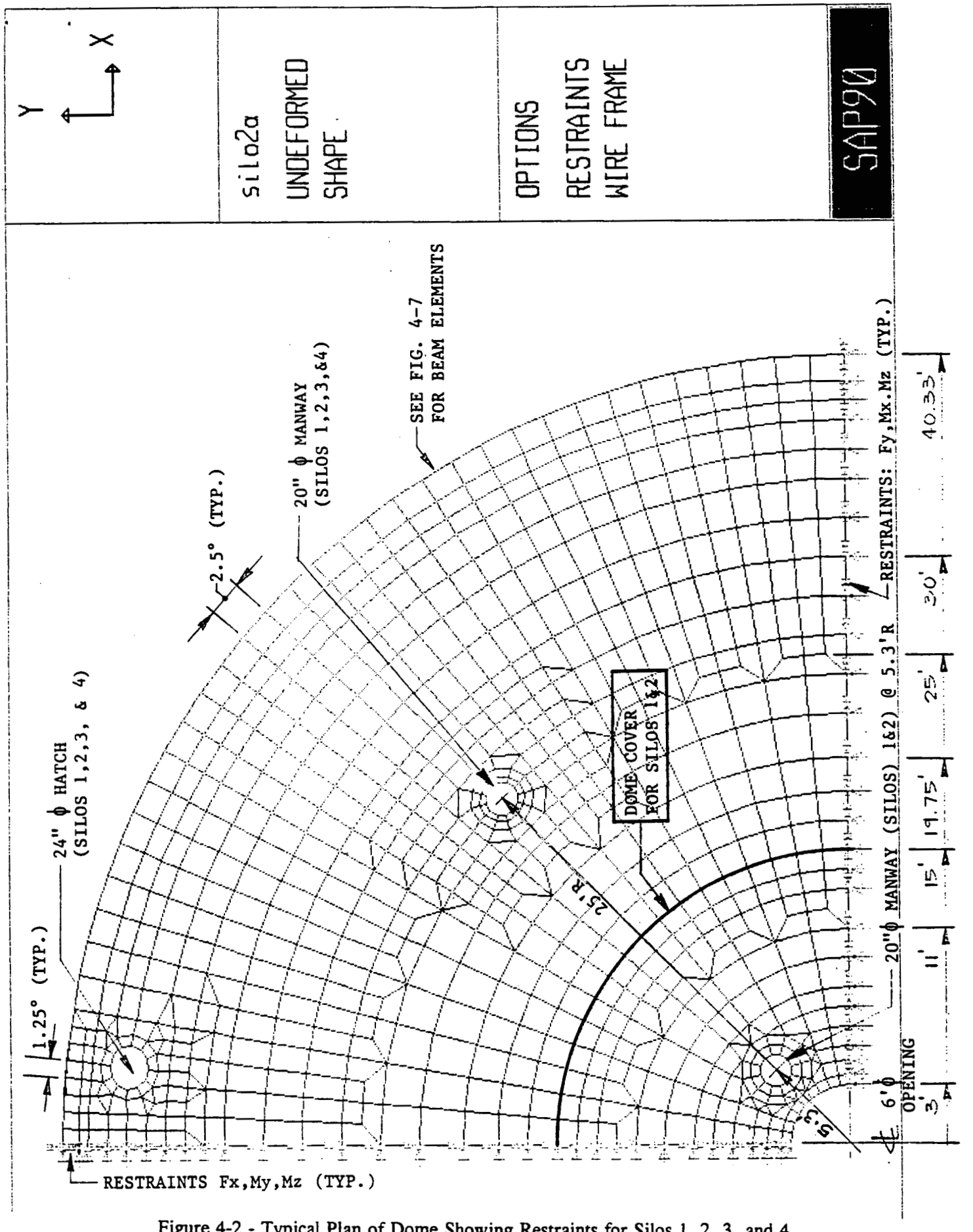


Figure 4-2 - Typical Plan of Dome Showing Restraints for Silos 1, 2, 3, and 4

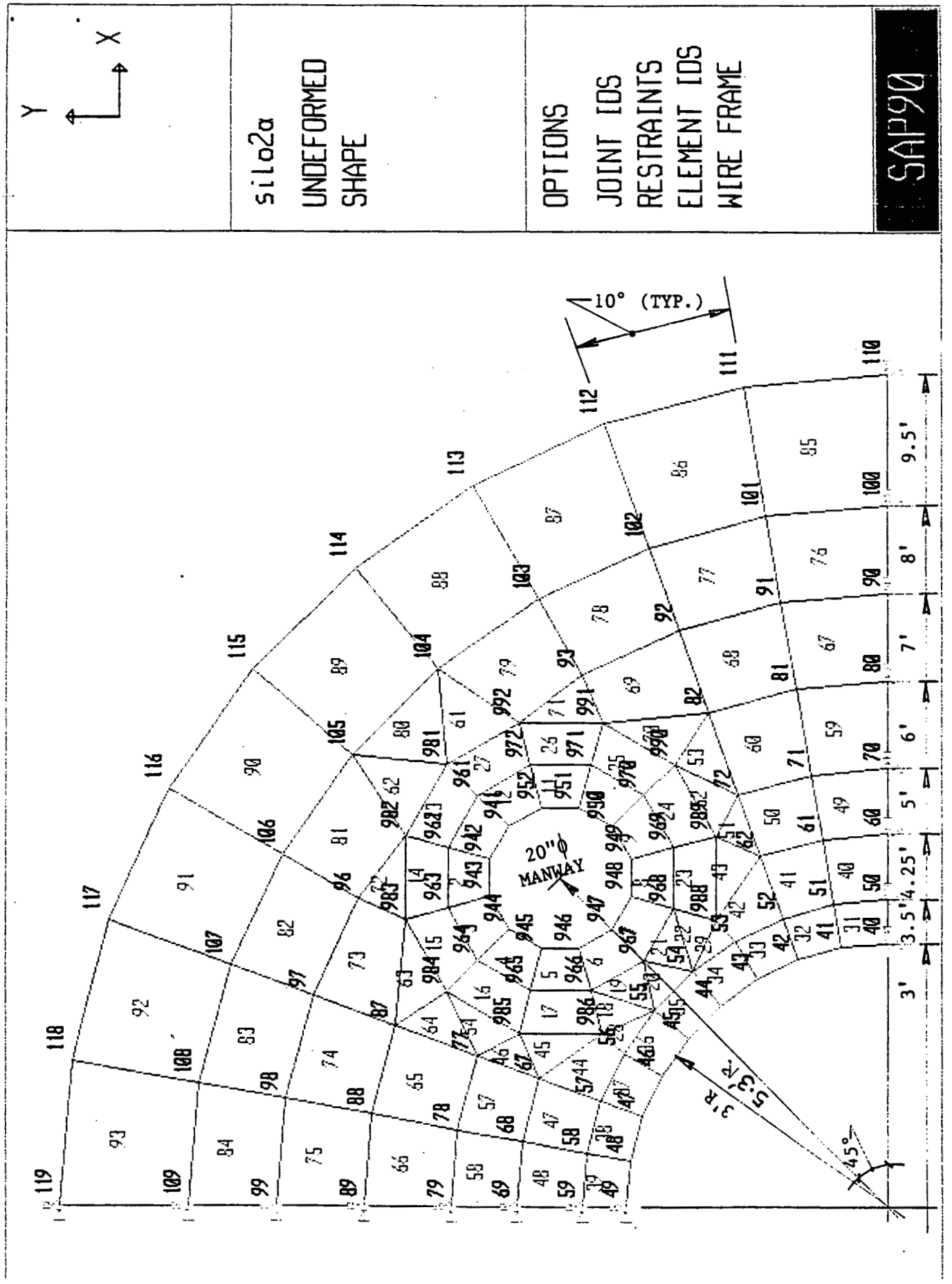


Figure 4-3 - Detail at Off-Center Manway for Silos 1 and 2

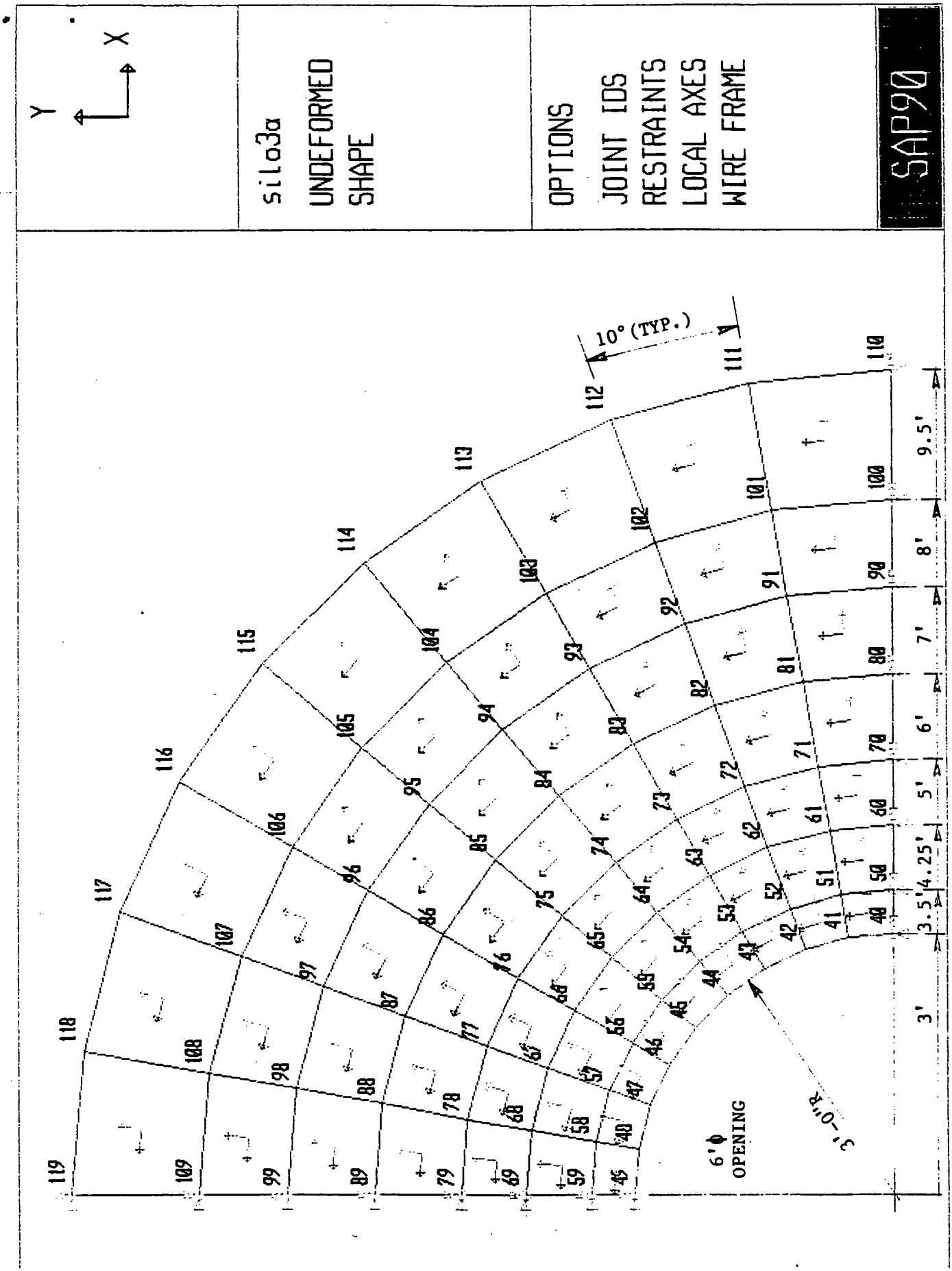


Figure 4-4 - Detail at Center for Silos 3 and 4

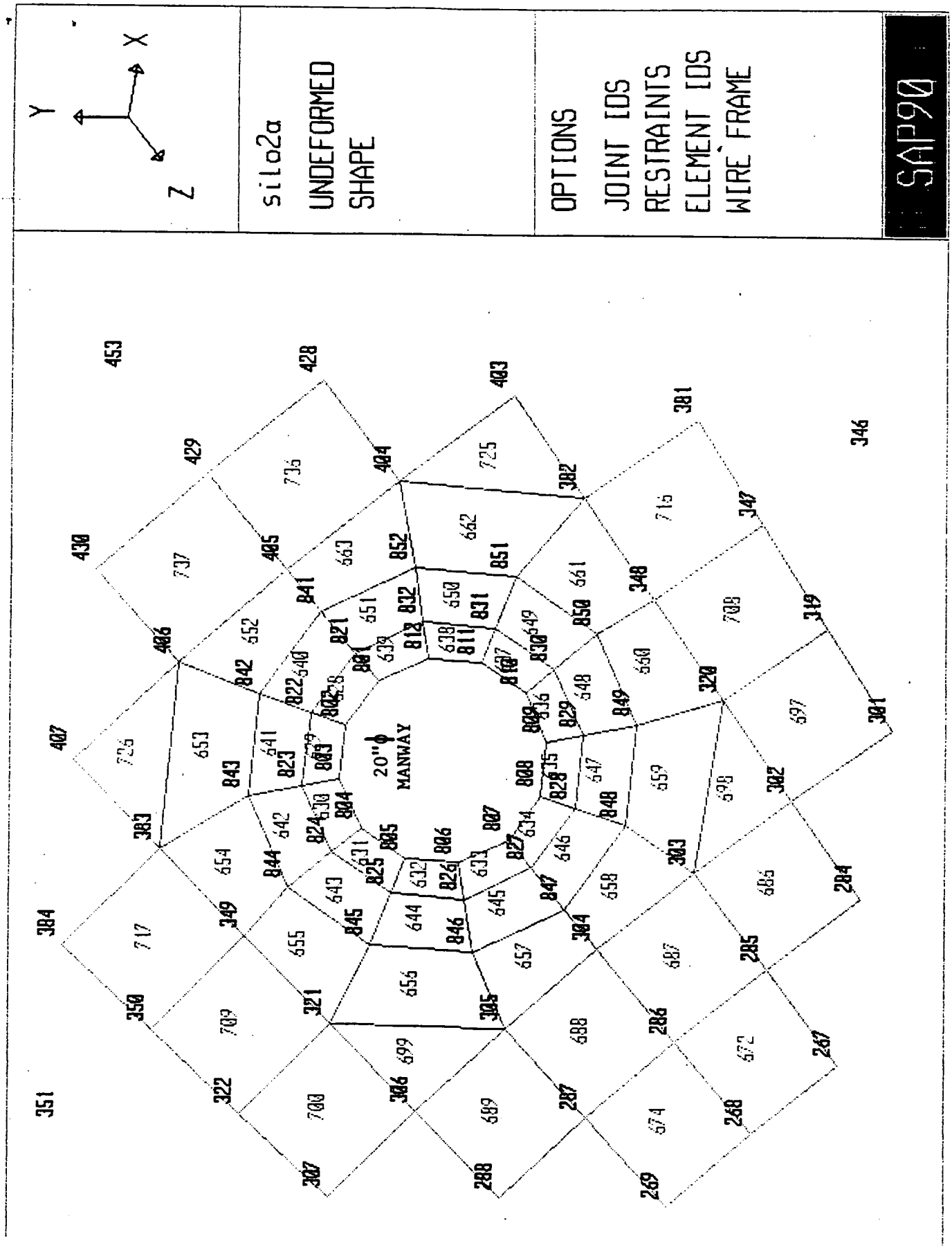


Figure 4-5 - Detail at 20-Inch Diameter Manway for Silos 1, 2, 3, and 4

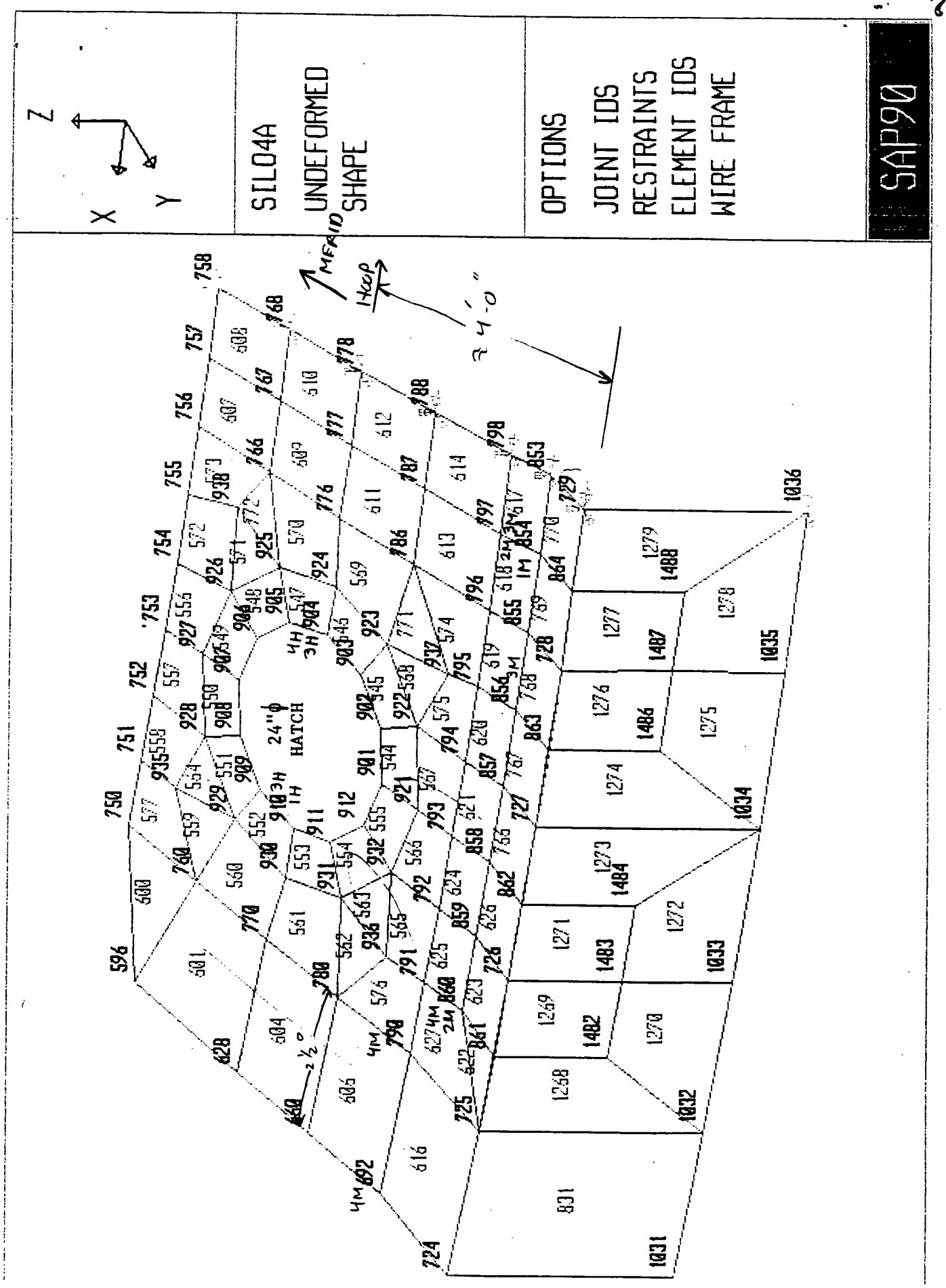


Figure 4-6 - Detail at 24-Inch Diameter Hatch for Silos 1, 2, 3, and 4

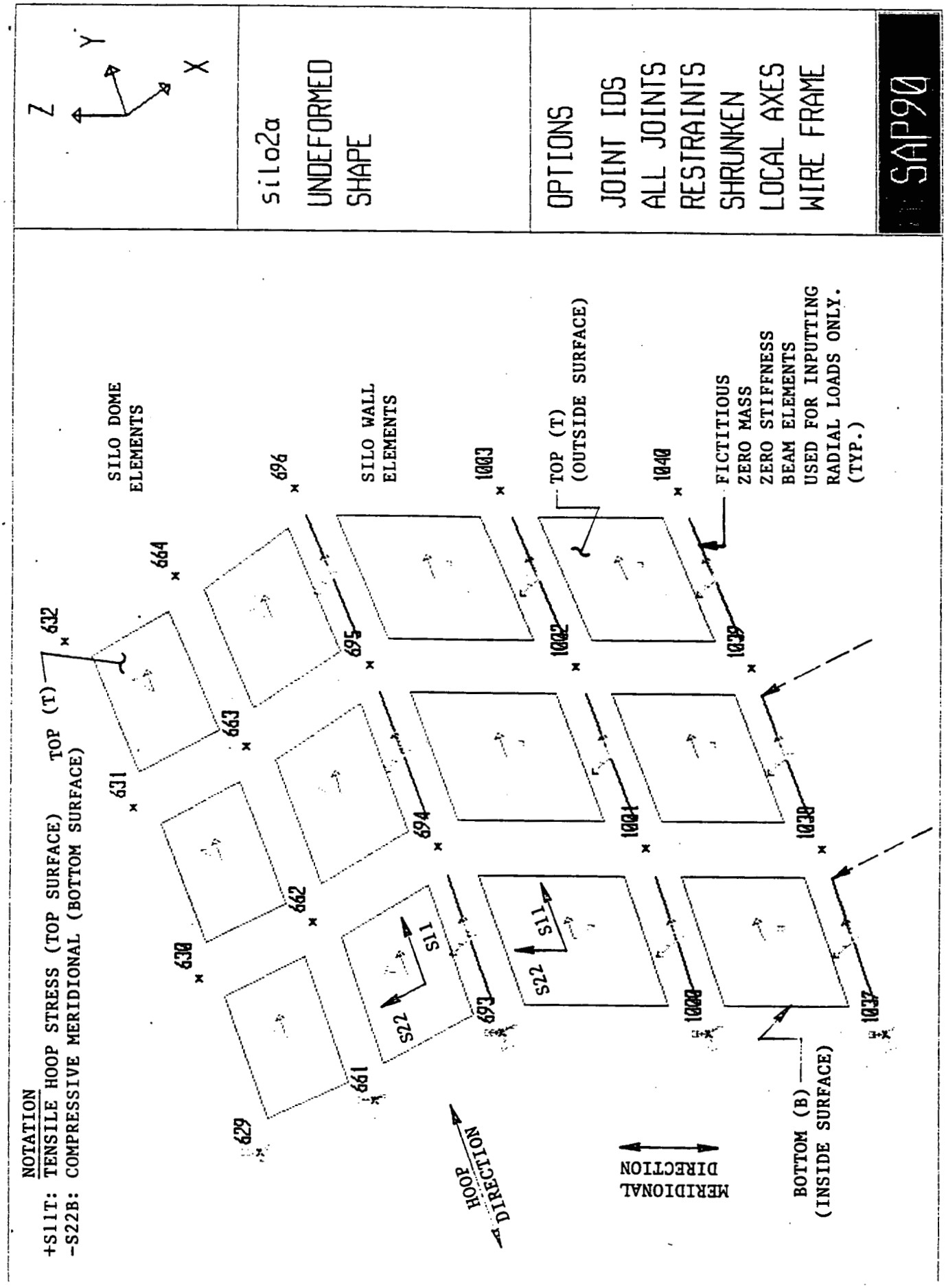


Figure 4-7 - Detail of Model Showing Local Axes and Stress Components

9) The contents inside the silo will be level at the depths as noted in Subsection 4.4.

10) The silos are classified as a low-hazard facility as designated in UCRL 15910.

11) Finite element formulation is based on shell elements combining membrane and plate-bending behavior.

4.3 Evaluation of Existing NDT Results

The 1986 Camargo test results were obtained by Muenow and Associated and are contained in (Muenow & Associates 1985a) for Silos 1 and 2 and in (Muenow & Associates 1985b) for Silos 3 and 4.

The test results were presented separately for the dome and wall at selected test points. Since the model used is a quarter model, averaged values of the test results were developed to represent typical values for the elements. The results included concrete strengths based on pulse velocities, concrete thicknesses, percentage of prestress wire loss, and crack data.

Dome tests were conducted at 30 degrees diametrical lines at approximately 20 points on each test line. Wall tests were conducted at 15-degree intervals along the circumference and at 1-foot intervals to the full depth of the wall.

The NDT test results taken at various points on the dome and the wall are shown in individual calculation packages for each silo.

Figures 4-8, 4-9, 4-10, and 4-11 show a summary of the data as used for the finite element model for Silos 1, 2, 3, and 4, respectively.

4.4 Loading Conditions and Loading Combinations

The following loading conditions were included:

1) Self Weight (SW)
2) Live Loads (LL)
3) Prestress Loads (PL)
4) Content Loads (CL)
5) Wind Loads (WL)
6) Earthquake Loads (EQK)
7) Embankment Loads (EML) (Silos 1 and 2 only)
8) Temperature Loads (TL)

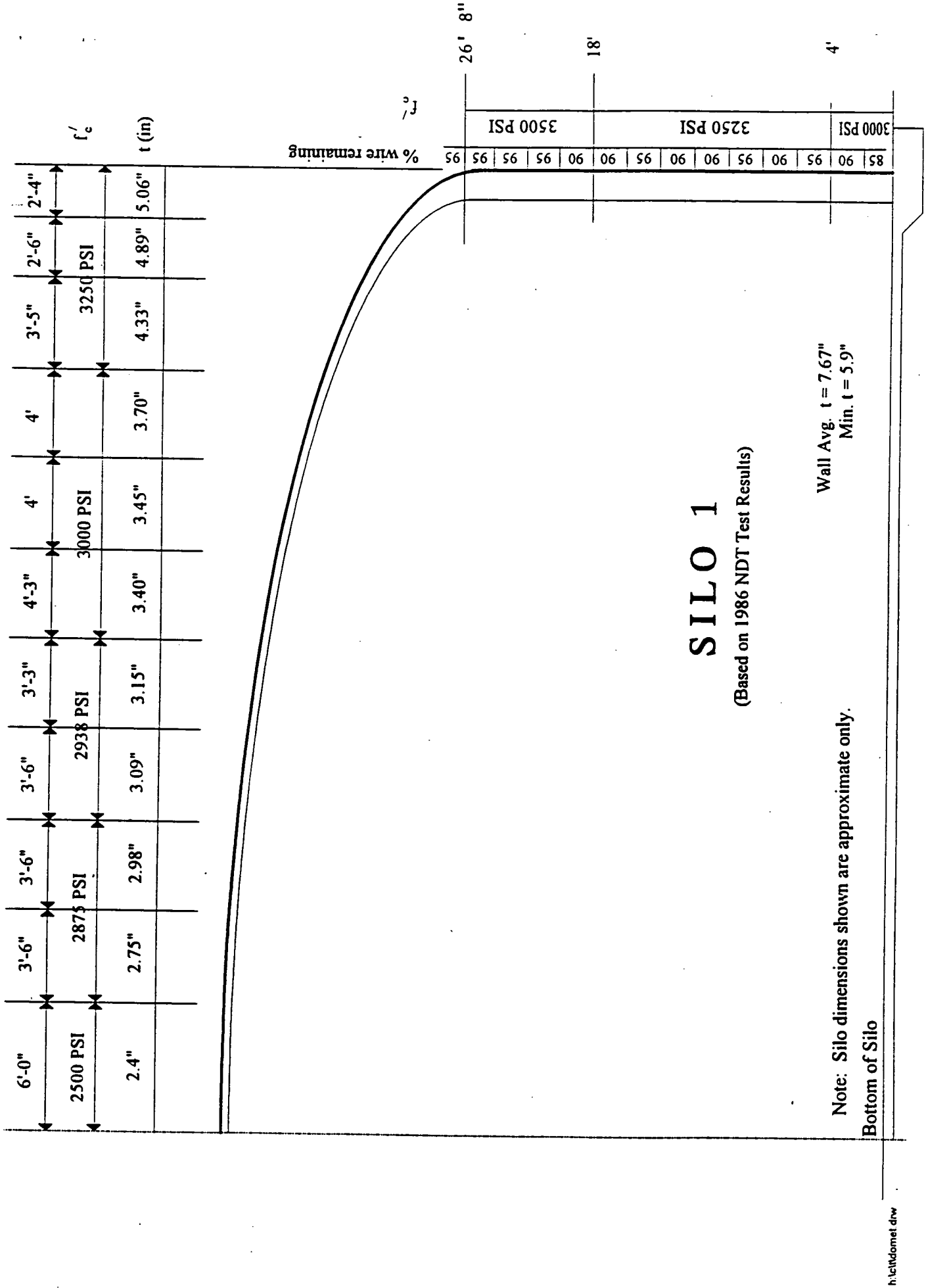


Figure 4-8 - Summary of Material Data for Silo 1

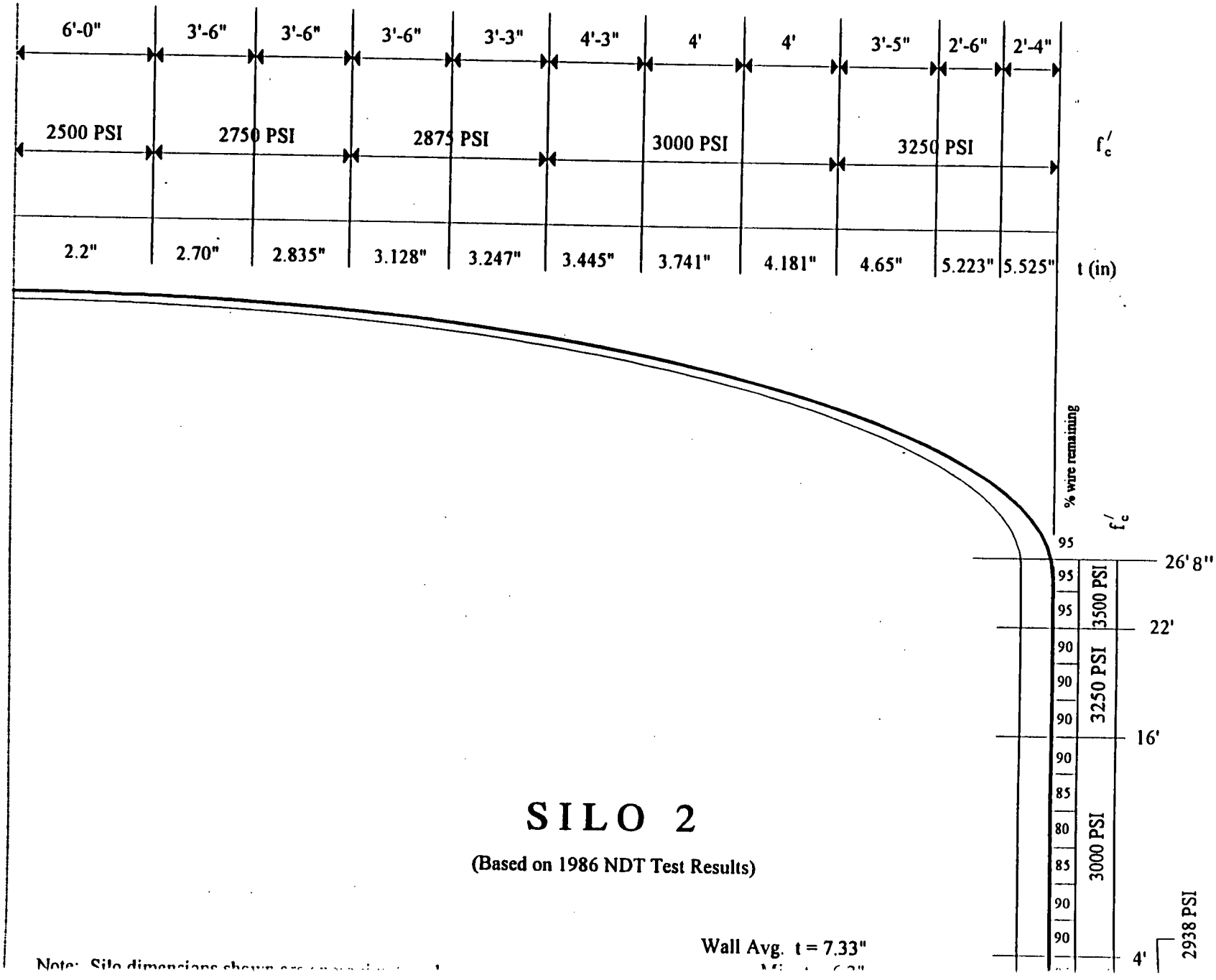
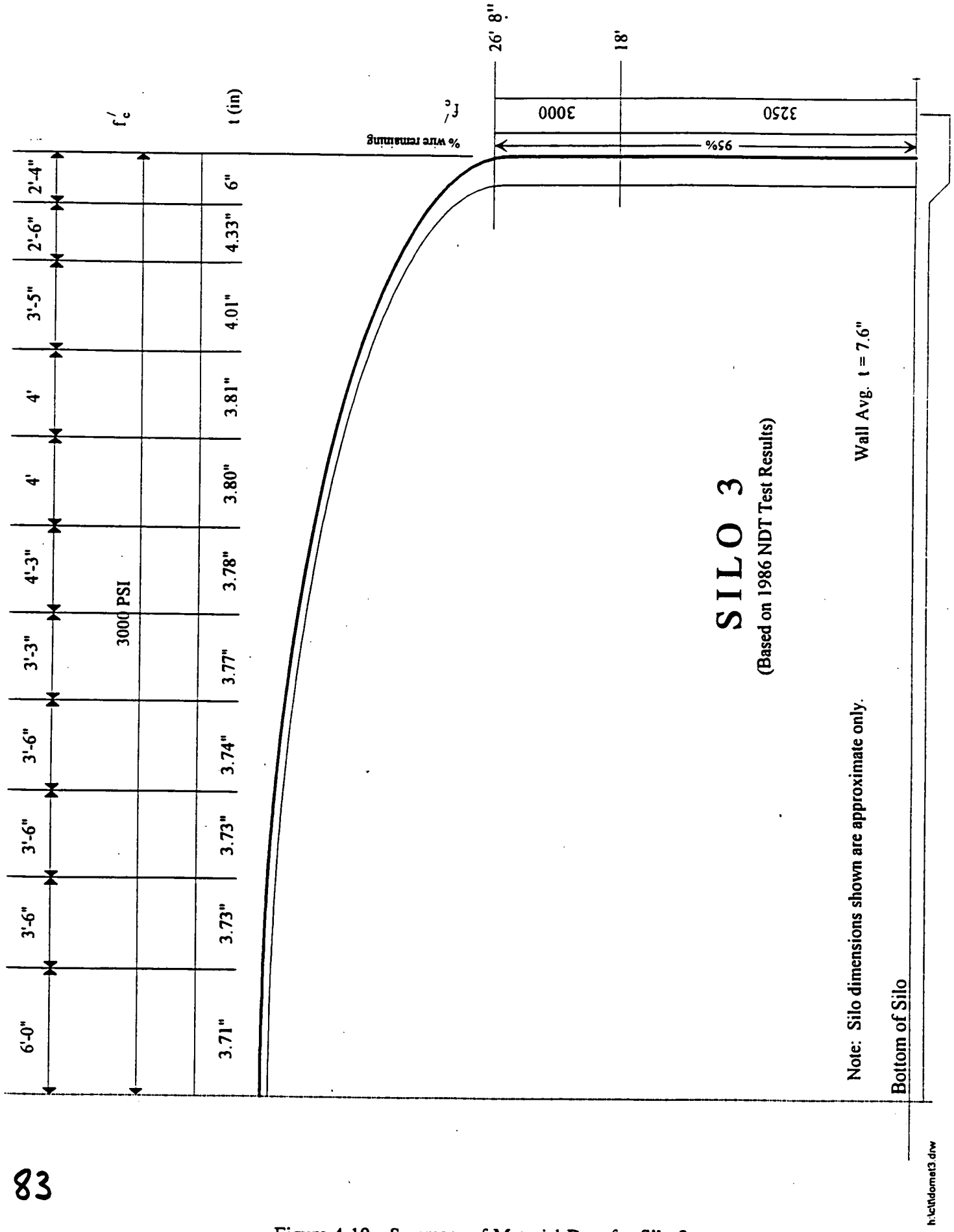


Figure 4.0 - Summary of Material Data for Silo 2

2224



83

Figure 4-10 - Summary of Material Data for Silo 3

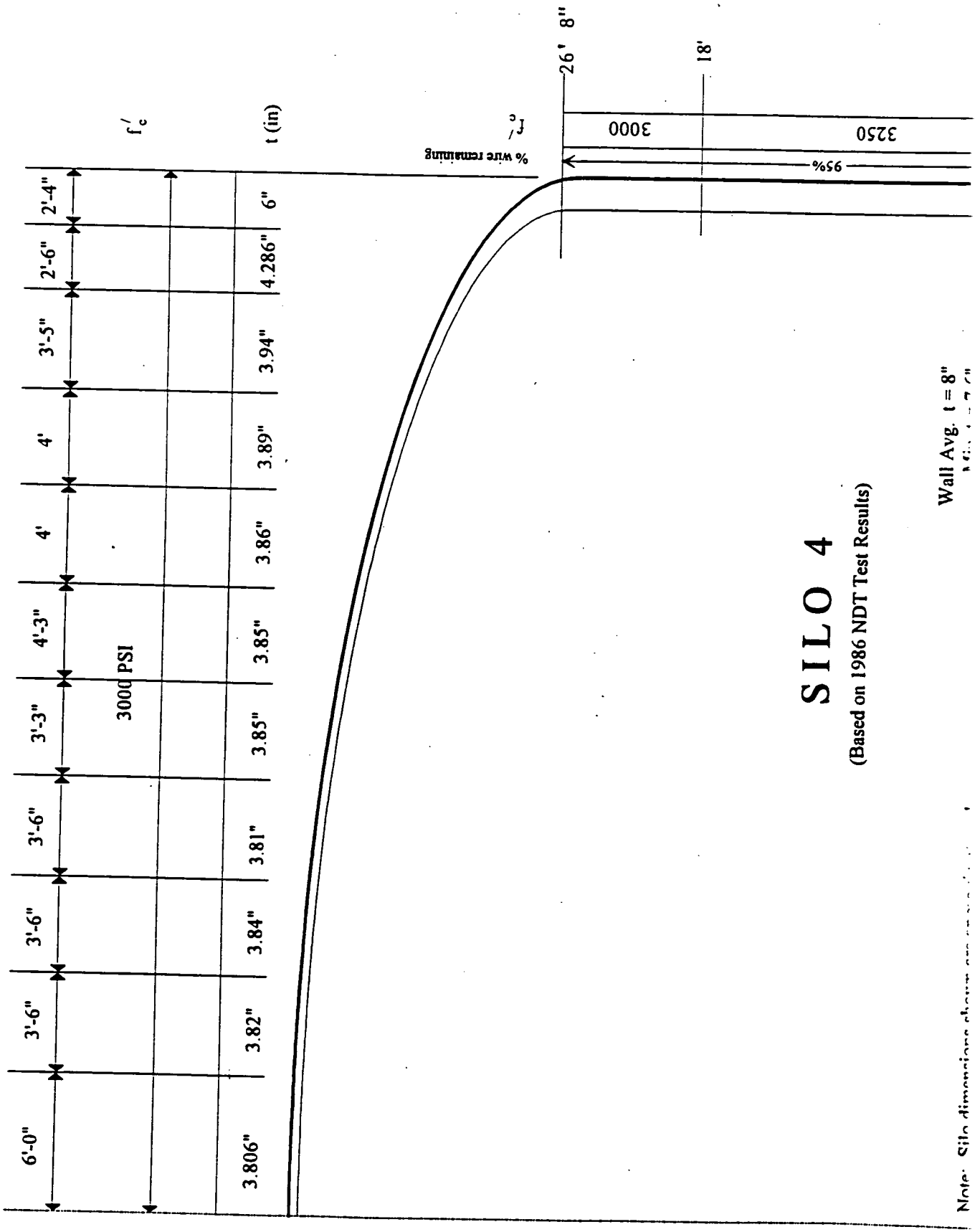


Figure 4-11 - Summary of Material Data for Silo 4

The following loading combinations were included:

Silos 3 and 4 (DL=SW+PL):

1) DL
2) DL + LL
3) DL + WL
4) 0.75 (DL + EQK)
5) ~~0.75 (DL + TL)~~
6) DL + CL
7) DL + LL + CL
8) 0.75 (DL + LL + CL + EQK)
9) 0.75 (DL + LL + CL + WL)
10) ~~.75 (DL + LL + CL + TL)~~

Silos 1 and 2 (DL=SW+PL+EML)

1) DL
2) DL + LL
3) .75 (DL+EQK)
4) DL + CL
5) DL + LL + CL
6) ~~.75 (DL + LL + CL + TL)~~
7) .75 (DL + LL + CL + EQK)
8) ~~.75 (DL + TL)~~

Note:
1. Silos 3 and 4 have no embankment loads.
2. For Silos 1 and 2, load combinations with wind loads were omitted as not critical, since the wind is acting on the dome portion only.
3. Silos 1 and 2 were not analyzed for different configurations of the embankment height including the case of no embankment.
4. The weight of dome cover and foam insulation was included in the dead load for Silos 1 and 2.
5. Load combinations with temperature loads (LC-6 and LC-8) for Silos 1 and 2 were not significant since they are insulated by the berm on one side and the contents on the other side. Loading combinations with temperature loads (LC-5 and LC-10) for Silos 3 and 4 also were not significant. The results for these combinations are, therefore, not included.

Each loading condition is described briefly as follows:

1) Self Weight (SW): This load includes the self weight of concrete. For Silos 1 and 2, the weight of dome cover and foam cover was added. Dead load due to self weight of concrete was automatically included in the analysis.

2) Live Load (LL): Roof live load of 20 psf was used over the dome surface only (PARSONS 1993a). Live loads were applied as joint loads using tributary areas.

3) Prestress Load (PL): The vertical prestress loads and horizontal wire winding loads were based on the number and diameter per details shown in Preload Inc. drawings. Prestress loss was also included. The wire loads were proportioned in accordance with wire loss data from test reports

(Muenow & Associates 1985a, b). Prestress loads at interior joints were applied as span lo on fictitious beam elements and as joint loads at end joints (see Figure 4-7).

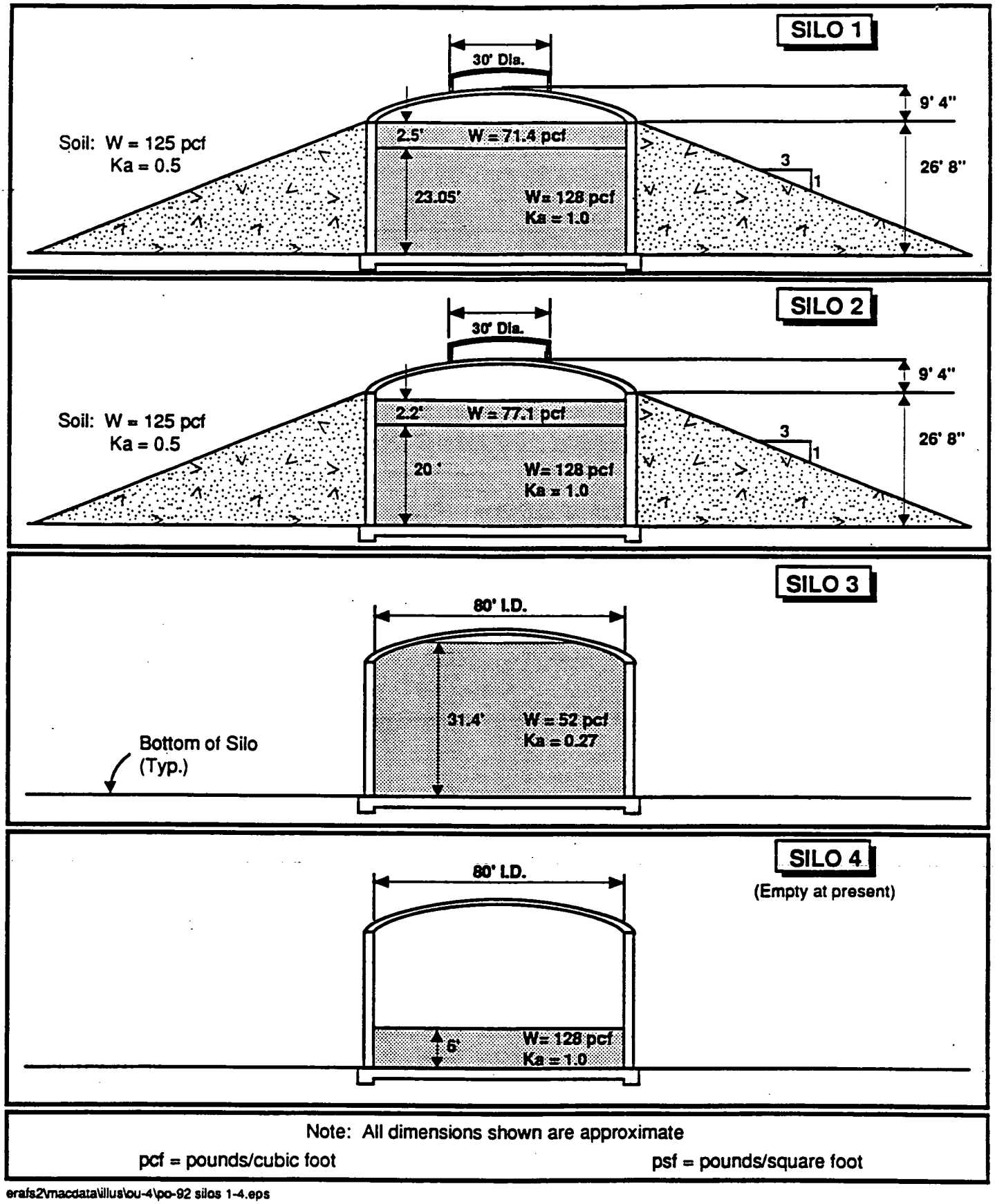
4) Content Loads (CL): The content loads were based on the depth and density of content shown in Figure 4-12. For Silos 1 and 2 the information from the OU-4 CDR (PARSONS 1 was used for the depth and density of contents and bentogrout. For Silo 4, the height of contents was taken as 6 feet. The density and unit weights were taken the same as for the 1 contents. Content loads were applied as potential loads in the SAP90 model.

5) Wind Loads (WL): Wind loads were based on wind velocity of 80 miles per hour (OBE Wind pressures were based on using exposure C and the procedures of ASCE 7-88 (ASCE). Silos 1 and 2, wind load is not critical. Wind loads were applied for Silos 3 and 4 only. W hazard curve was based on UCRL 53526 (UCRLa). Wind loads on dome surface were basec ASCE paper (ASCE 1972) and ASCE 7-88 (ASCE).

6) Earthquake Loads (EQK): Earthquake loads were based on the procedures of UCRL 15 (UCRL 1990). A response spectrum analysis was made using the site-specific response spe for the FEMP taken from UCRL 53582 (UCRLb) and site-specific peak ground acceleration v of 0.13 g for the FEMP taken from UCRL 15910, as shown in Figure 4-13. Ten modes v considered. The mass of contents was lumped at the wall nodes. Conservative approximat were made in the load combinations which include earthquake loads. Earthquake loads v analyzed using response spectrum and modal superposition methods using separate runs. Vert accelerations were taken as 2/3 of the horizontal accelerations. 10

7) Embankment Loads (EML): Embankment loads were applied for Silos 1 and 2 only as shc in Figure 4-12. The height of the embankment was taken to the full height of the silo wall. soil density (125 pcf) and horizontal earth pressure coefficients (0.5) were based on the OU Project Order 92 Soil Report (Nutting 1993). Embankment loads were approximated and app as potential loads in the SAP90 model.

8) Temperature Loads (TL): The temperature loads were based on a maximum annual temperat differential of ± 40 degrees F. The temperature load was applied as a uniform expansion contraction due to change of temperature throughout the silo structure. Temperature loads w applied as potential loads with the SAP90 model. Temperature variations through the thickn of the elements were not considered. Temperature loads were not critical.



erafs2\macdata\illus\ou-4\po-92 silos 1-4.eps

Figure 4-12 - Depth of Contents for Silos 1, 2, 3, and 4

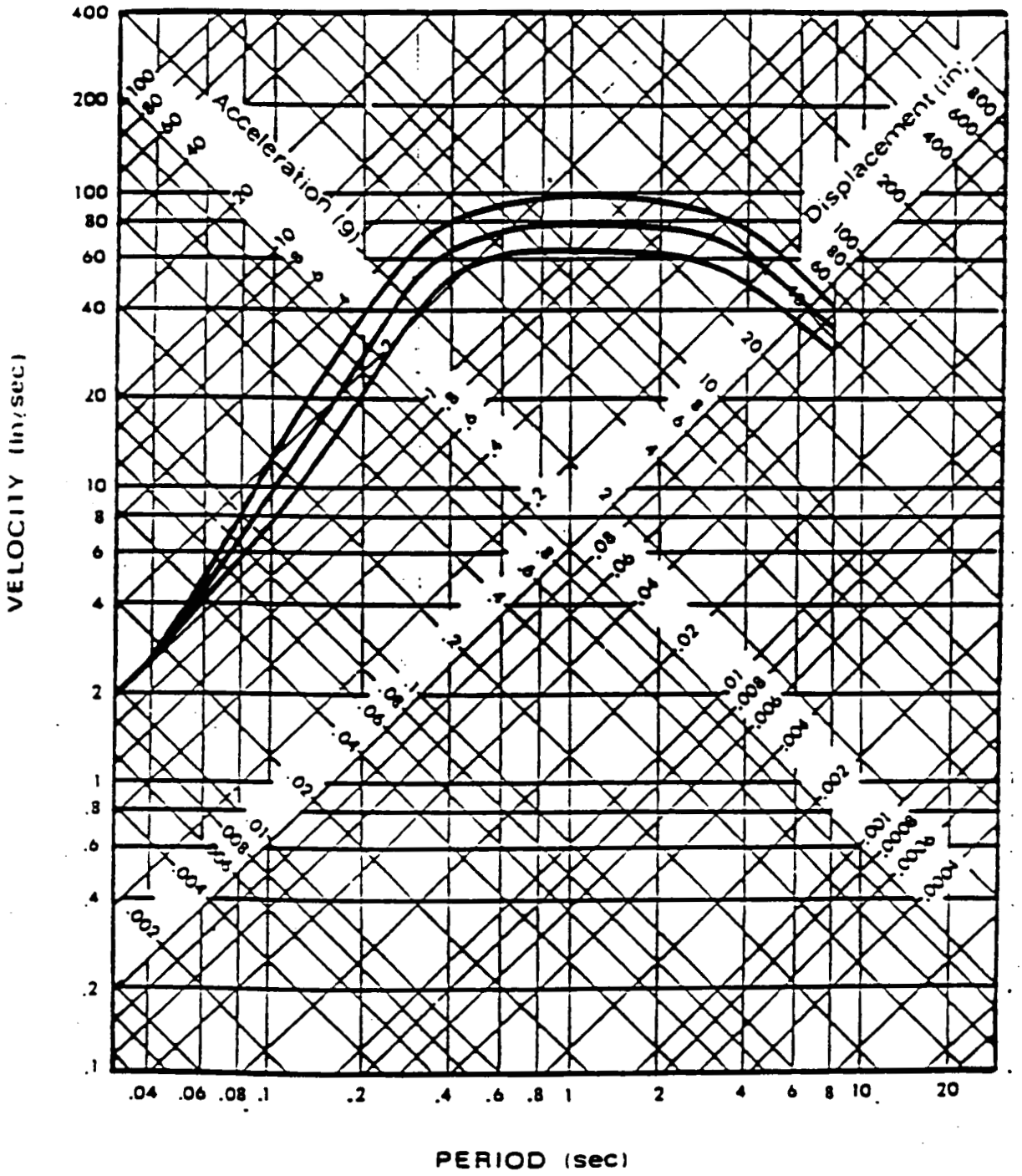


Figure 4-13 - Design Response Spectrum Scaled to 1.0 g (2%, 5%, and 10% of Critical Damping)
FEMP (UCRL 53582)

4.5 Allowable Stresses

4.5.1 Dome Buckling

prestress concrete struct...

Dome buckling stress was calculated using the elastic theory of dome shell stability based on ACI 344-W (ACI 1988). This method accounts for creep, imperfections, material variability, cracking, and nonlinearity. The buckling load was also calculated by a second method based on ACI SP 67 (ACI 1981). The most conservative value of the buckling load corresponds to about 100 psf for a dome based on a constant thickness of at least 2-1/2 inches and is well above the maximum anticipated loading.

4.5.2 Allowable Stresses in Concrete

Concrete Shell Buckling

The silos were constructed as circular- wire-wrapped prestressed concrete tanks and post-tensioned by vertical tendons. The walls have no vertical reinforcement or metal diaphragm. The allowable stresses were based on the alternate design provisions of ACI 318 and ACI 344-W applicable for prestressed concrete shell structures of this type of construction. The allowable tensile stresses in the dome are based on plain concrete (ACI 1989, NAWY 1989).

The allowable hoop and meridional, compressive and tensile stresses, and the allowable shear stresses for the wall and the dome are summarized in Table 4-1. The concrete strengths are based on 1986 Camargo test results as noted in Subsection 4.3.

4.5.3 Allowable Stresses in Reinforcement

The allowable stresses in rebars and welded wire mesh were taken as 24,000 psi and provisions of ACI 318.

4.5.4 Allowable Stresses in Prestress Wires

The allowable stress in prestressed wires was based on ACI 344-W assuming field die-drawn wires corresponding to ASTM A821 or equal, with specified tensile strength, fpu of 218,000 psi.

The allowable stress for prestress wires was taken as 152,000 psi corresponding to 0.7 fpu.

Table 4-1 - Allowable Stresses in Concrete

ALLOWABLE STRESS			f'_c (PSI)				
			3500	3250	3000	2875	2750
DOME							
Hoop compr. (-S11) (NAWY, pg. 678)	$0.2\ f'_c$	PSI	700	650	600	575	550
Merid. compr. (-S22) (NAWY pg. 678)		KSF	(100.8)	(93.6)	(86.4)	(82.8)	(79.2)
Hoop tension (+S11) (ACI 318.1, 6.2.1[a])	*0.03 f'c or $1.91\sqrt{f'_c}$	PSI	105	97.50	90	86.25	82.5
Merid. tension (+S22) (ACI 318.1, 6.2.1[a])		KSF	(15.1)	(14.0)	(12.96)	(12.42)	(11.88)
WALL							
Hoop compr. (-S11) (ACI 344, 2.3.3.2[d])	$.45\ f'_c$	PSI	1575	1463	1350	1294	1238
Merid. compr. (-S22) (ACI 344, 2.3.3.2[d])		KSF	(226.8)	(210.7)	(194.4)	(186.3)	(178.3)
Hoop tension (+S11) (ACI 318, 18.4.2[b])	** $6\sqrt{f'_c}$	PSI	355	342	329	322	315
Merid. tension (+S22) (ACI 318, 18.4.2[b])		KSF	(51.1)	(49.1)	(47.2)	(46.4)	(45.4)
Out of plane shear (ACI 318, A.3.1[b])	$1.1\sqrt{f'_c}$	PSI	65	63	60	59	58
		KSF	(9.4)	(9.1)	(8.6)	(8.5)	(8.4)

Notes: *Conservative value of 0.03 f'c is used: (ACI 1940)

**Stress at which concrete will crack.

SECTION 5

COMPUTER SOLUTIONS

5.1 Summary of Stresses

The results of structural analyses on Silos 1, 2, 3, and 4 are summarized to include stresses and displacements for all the applicable loading conditions.

The tensile (+ve) and compressive (-ve), hoop stress (S11) and meridional stress (S22), for the top (T) and bottom (B) surface were evaluated for each element for all load cases separately for the dome and the wall for silos 1, 2, 3 and 4.

Tables 5-1 and 5-2 show the enveloped values of the hoop and meridional **stresses for Silo 1 Dome and wall** respectively.

Tables 5-3 and 5-4 show the enveloped values of the hoop and meridional **stresses for Silo 2 Dome and wall** respectively.

Tables 5-5 and 5-6 show the enveloped values of the hoop and meridional **stresses for Silo 3 Dome and wall** respectively.

Tables 5-7 and 5-8 show the enveloped values of the hoop and meridional **stresses for Silo 4 Dome and wall** respectively.

Figures 5-1 through 5-4 show typical **stress contour plots for the Silo 1 Dome and Wall for LC-5 (DL+LL+CL)**, for the stress components S11B and S22B.

Figures 5-5 through 5-8 show typical **stress contour plots for the Silo 2 Dome and Wall for LC-5 (DL+LL+CL)**, for the stress components S11B and S22B.

Figures 5-9 through 5-12 show typical **stress contour plots for the Silo 3 Dome and Wall for LC-7 (DL+LL+CL)**, for the stress components S11B and S22B.

Figures 5-13 through 5-16 show typical **stress contour plots for the Silo 4 Dome and Wall for LC-7 (DL+LL+CL)**, for the stress components S11B and S22B.

Note: Similar stress contour plots were obtained for the stress components S11T and S22T.

Table 5-1 - Silo 1 - Summary of Maximum Stresses - Dome

	(-93.6)		Hoop Stress (KSF)				(+14)	(24)
	-S11T	%	+S11T	%	-S11B	%	+S11B	f_s
LC-1	-40	-	-3.25	-	-85.6	-	6.1	
Jt. No.	727		448		864		910	
LC-2	-55	-	4.53	-	-77.5	-	-13	
Jt. No.	727		864		864		910	
LC-3	-45	-	-1.87	-	41.5	-	5.88	
Jt. No.	727		864		901		910	
LC-4	-60	-	-3.1	-	-82.8	-	15.9	6.33
Jt. No.	727		423		864		910	(3)
LC-5	-55	-	4.78	-	-74.8	-	11	
Jt. No.	727		864		864		910	
LC-7	-37.5	-	4.62	-	-34	-	415	
Jt. No.	727		864		864		910	

Next to Hatch

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3,$ psi, as shown in Table 4-1 and Figure 4-8. Allowable stress in steel = 24 KSI.
2) % indicates overstress in concrete section.
3) f_s indicates stress in reinforcement (KSI).
4) Joint number shown in second row of each load case indicates approximate location where maximum stress occurs.
5) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC and LC-8 are not critical.

Table 5-1 - Silo 1 - Summary of Maximum Stresses - Dome (Continued)

	(-93.6)		Meridional Stress (KSF)				(+14)	(24)
	-S22T	%	+S22T	%	-S22B	%	+S22B	f_s
LC-1	-50	-	3.4	-	-17.7	-	35	13.93
Jt. No.	727		751		753		854	(3)
LC-2	-40	-	5.8	-	-34.7	-	20.1	8.0
Jt. No.	854		726		728		854	(3)
LC-3	-35	-	2.87	-	-13	-	27.7	11.02
Jt. No.	727		755		753		854	(3)
LC-4	-60	-	4.38	-	-15.7	-	45.2	17.99
Jt. No.	727		532		743		854	(3)
LC-5	-48.2	-	3.26	-	-24.2	-	30.3	1.31
Jt. No.	854		864		728		854	(3) 12.1
LC-7	-34.9	-	4.76	-	-15.6	-	24.1	9.59
Jt. No.	854		864		728		854	(3)

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surface
S22B - Meridional Stress bottom surface

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3{,}250$ psi, as shown in Table 4-1 and Figure 4-8. Allowable stress in steel = 24 KSI.
2) % indicates overstress in concrete section.
3) f_s indicates stress in reinforcement (KSI).
4) Joint number shown in second row of each load case indicates approximate location where the maximum stress occurs.
5) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC-6 and LC-8 are not critical.

Table 5-2 - Silo 1 - Summary of Maximum Stresses - Wall

	(-194.4)		Hoop Stress (KSF)				(+47.2)	
	-S11T	%	+S11T	%	-S11B	%	+S11B	%
LC-1	-206	6	0.21	-	-194	-	0.17	-
Jt. No.	1357		1468		1357		1478	
LC-2	-206	6	4.2	-	-194	-	0.17	-
Jt. No.	1357		864		1357		1478	
LC-3	-154	-	0.16	-	-145	-	0.13	-
Jt. No.	1357		1480		1357		1478	
LC-4	-60	-	0.02	-	-48.6	-	0.01	-
Jt. No.	727		1480		1487		1478	
LC-5	-55	-	4.7	-	-40.5	-	0.01	-
Jt. No.	727		864		1487		1478	
LC-7	-37.5	-	4.53	-	-29.5	-	0.01	-
Jt. No.	727		864		1487		1478	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top sur
S22B - Meridional Stress bottom sur

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3$, psi, as shown in Table 4-1 and Figure 4-8.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects L and LC-8 are not critical.

Table 5-2 - Silo 1 - Summary of Maximum Stresses - Wall (Continued)

	(-194.4)		Meridional Stress (KSF)				(+47.2)	
	-S22T	%	+S22T	%	-S22B	%	+S22B	%
LC-1	-154	-	0.62	-	-57	-	109	130
Jt. No.	1396		1101		1109		1396 4' from base	(5)
LC-2	-154	-	5.09	-	-54	-	108	128
Jt. No.	1396		726		1109		1396	(5)
LC-3	-115	-	0.98	-	-42	-	82.0	73
Jt. No.	1396		1101		1109		1396	(5)
LC-4	-60	-	-5.9	-	-39	-	6.12	-
Jt. No.	727		1103		1109		728	
LC-5	-56	-	0.86	-	-32.5	-	-2.59	-
Jt. No.	1036		726		1109		1007	
LC-7	-42	-	1.58	-	-25	-	-1.68	-
Jt. No.	1036		728		1145		1007	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surface
S22B - Meridional Stress bottom surface

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3{,}000$ psi, as shown in Table 4-1 and Figure 4-8.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where the maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC-6 and LC-8 are not critical.
5) Loading combination without contents is critical. Embankment load must be reduced before contents of tank are removed for load cases LC-1, LC-2, and LC-3.

Table 5-3 - Silo 2 - Summary of Maximum Stresses - Dome

	(-93.6)		Hoop Stress (KSF)				(+14)	
	-S11T	%	+S11T	%	-S11B	%	+S11B	%
LC-1	-90	-	4.17	-	-89.2	-	13	-
Jt. No.	728		864		864		727	
LC-2	-85	-	12.3	-	-81.2	-	14	-
Jt. No.	725		864		864		727	
LC-3	-70	-	4.02	-	-66.0	-	0	-
Jt. No.	725		864		864		727	
LC-4	-95	1	1.64	-	-90.8	-	0	-
Jt. No.	725		864		864		727	
LC-5	-90	-	9.8	-	-82.8	-	14	-
Jt. No.	725		864		864		725	
LC-7	-65	-	8.27	-	-61.4	-	11	-
Jt. No.	725		864		864		863	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surf
S22B - Meridional Stress bottom surf

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3,$ psi, as shown in Table 4-1 and Figure 4-9.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC and LC-8 are not critical.

Table 5-3 - Silo 2 - Summary of Maximum Stresses - Dome (Continued)

	(-93.6)		Meridional Stress (KSF)				(+14)	
	-S22T	%	+S22T	%	-S22B	%	+S22B	f_s
LC-1	-49	-	3.98	-	-15.5	-	32	12.73
Jt. No.	854		734		743		854	(3)
LC-2	-36.6	-	13.1	-	-32.9	-	14	5.57
Jt. No.	854		863		728		854	(3)
LC-3	-42.3	-	3.3	-	-11.5	-	30	11.93
Jt. No.	854		734		743		854	(3)
LC-4	-64.7	-	4.69	-	-16.1	-	34	13.53
Jt. No.	854		734		743		860	(3)
LC-5	-42.5	-	7.10	-	-27.5	-	24	9.55
Jt. No.	854		861		728		854	(3)
LC-7	-30	-	6.99	-	-18.7	-	15	5.97
Jt. No.	854		863		728		860	(3)

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surface
S22B - Meridional Stress bottom surface

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3{,}250$ psi, as shown in Table 4-1 and Figure 4-9. Allowable stress in steel = 24 KSI.
2) % indicates overstress in concrete section.
3) f_s indicates stress in reinforcement (KSI).
4) Joint number shown in second row of each load case indicates approximate location where the maximum stress occurs.
5) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC-6 and LC-8 are not critical.

Table 5-4 - Silo 2 - Summary of Maximum Stresses - Wall

	(-186.3)		Hoop Stress (KSF)				(+46.4)	
	-S11T	%	+S11T	%	-S11B	%	+S11B	%
LC-1	-188	1	.16	-	-177	-	9.83	-
Jt. No.	1363		1456		1363		1472	
LC-2	-188	1	8.5	-	-177	-	9.83	-
Jt. No.	1363		864		1363		1472	
LC-3	-140	-	.74	-	-132	-	≃0	-
Jt. No.	1363		864		1363		1472	
LC-4	-38.5	-	≃0	-	-49.4	-	≃0	-
Jt. No.	1019		1456		1487		1472	
LC-5	-41.4	-	6.07	-	-41.8	-	≃0	-
Jt. No.	1333		864		1487		1472	
LC-7	-24	-	5.41	-	-30.7	-	1.33	-
Jt. No.	1002		864		1487		1479	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surf
S22B - Meridional Stress bottom surf

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 2,$ psi, as shown in Table 4-1 and Figure 4-9.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects L(and LC-8 are not critical.

$\frac{24000 psi}{8 inch} \times .017 in^2/in = 51 psi$ ⟷ for ½" ϕ rod @ 12" spacing 8" wall

Table 5-4 - Silo 2 - Summary of Maximum Stresses - Wall (Continued)

	(-186.3)		Meridional Stress (KSF)				(+46.4)	
	-S22T	%	+S22T	%	-S22B	%	+S22B	%
LC-1	-151	-	-.69	-	-53.5	-	105 = 729 psi	126
Jt. No.	1380		1103		1074		1384	(5)
LC-2	-151	-	6.56	-	-54	-	104	124
Jt. No.	1380		728		1076		1384	(5)
LC-3	-113	-	.02	-	-39.5	-	78.9	70
Jt. No.	1380		1103		1074		1384	(5)
LC-4	-72	-	8.21	-	-30	-	3.01	-
Jt. No.	727		726		1114		1027	
LC-5	-48	-	3.36	-	-36	-	-.21	-
Jt. No.	1370		728		727		1009	
LC-7	-42.5	-	3.53	-	-25	-	≃0	-
Jt. No.	727		728		727		1009	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surface
S22B - Meridional Stress bottom surface

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 2,875$ psi, as shown in Table 4-1 and Figure 4-9.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where the maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC-6 and LC-8 are not critical.
5) Loading combination without contents is critical. Embankment load must be reduced before contents of tank are removed for load cases LC-1, LC-2, and LC-3.

Table 5-5 - Silo 3 - Summary of Maximum Stresses - Dome

	(-86.4)		Hoop Stress (KSF)				(+12.96)	(24)
	-S11T	%	+S11T	%	-S11B	%	+S11B	f_s
LC-1	-77	-	2.3	-	-74.5	-	26.7	10.62
Jt. No.	901		423		901		910	(3)
LC-2	-44	-	-1.96	-	-63	-	13.3	5.29
Jt. No.	901		864		901		910	(3)
LC-3	-45	-	2.4	-	-86.9	-	41.1	16.35
Jt. No.	901		40		901		910	(3)
LC-4	-60	-	-1.62	-	-75.9	-	20.9	8.31
Jt. No.	901		423		864		904	(3)
LC-6	-40	-	-2.36	-	-72	-	28	11.14
Jt. No.	901		423		901		904	(3)
LC-7	-37.5	-	-0.7	-	-92.6	-	14.7	5.85
Jt. No.	901		864		864		904	(3)
LC-8	-45	-	-3.3	-	-69.1	-	11.8	
Jt. No.	901		864		864		904	
LC-9	-68	-	1.79	-	-80.8	-	31.8	12.65
Jt. No.	901		40		864		904	(3)

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surf.
S22B - Meridional Stress bottom surf.

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3,($ psi, as shown in Table 4-1 and Figure 4-10. Allowable stress in steel = 24 KSI.
2) % indicates overstress in concrete section.
3) f_s indicates stress in reinforcement (KSI).
4) Joint number shown in second row of each load case indicates approximate location where maximum stress occurs.
5) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC and LC-10 are not critical.

KSF x 6.94 → PSI

Table 5-5 - Silo 3 - Summary of Maximum Stresses - Dome (Continued)

	(-86.4)		Meridional Stress (KSF)				(+12.96)	(24) = 60.3 KSF (CONCRETE)
	-S22T	%	+S22T	%	-S22B	%	+S22B	f_s
LC-1	-45	-	8.93	-	-23.6	-	44 (305 PSI)	17.50
Jt. No.	692		734		937		856	(3)
LC-2	-42	-	2.61	-	-21.6	-	36	14.32
Jt. No.	692		939		987		856	(3)
LC-3	-72	-	17.70	-	-25.8	-	59.6	23.71
Jt. No.	858		734		937		854	(3)
LC-4	-35	-	6.96	-	-17.4	-	34	13.53
Jt. No.	858		734		937		856	(3)
LC-6	-45	-	8.25	-	-23.8	-	44	17.50
Jt. No.	692		734		937		856	(3)
LC-7	-42	-	2.07	-	-21.8	-	30	11.93
Jt. No.	692		525		937		856	(3)
LC-8	-30	-	1.78	-	-16.2	-	27.8	11.06
Jt. No.	692		525		937		856	(3)
LC-9	-40	-	12.7	-	-19.5	-	45.1	17.94
Jt. No.	692		734		937		854	(3)

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surface
S22B - Meridional Stress bottom surface

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3{,}000$ psi, as shown in Table 4-1 and Figure 4-10. Allowable stress in ~~concrete~~ STEEL = 24 KSI.
2) % indicates overstress in concrete section.
3) f_s indicates stress in reinforcement (KSI).
4) Joint number shown in second row of each load case indicates approximate location where the maximum stress occurs.
5) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC-5 and LC-10 are not critical.

Table 5-6 - Silo 3 - Summary of Maximum Stresses - Wall

	(-210.7)		Hoop Stress (KSF)				(+49.1)	
	-S11T	%	+S11T	%	-S11B	%	+S11B	%
LC-1	-98.9	-	0	-	-98.9	-	0	-
Jt. No.	1333		1444		1341		1450	
LC-2	-98.9	-	0	-	-98.9	-	0	-
Jt. No.	1333		1444		1341		1450	
LC-3	-99.3	-	0	-	-99.4	-	0	-
Jt. No.	1335		1446		1341		1444	
LC-4	-73.9	-	0	-	-73.7	-	0	-
Jt. No.	1333		1446		1340		1479	
LC-6	-77.8	-	0	-	-77.8	-	0	-
Jt. No.	1333		1444		1341		1450	
LC-7	-77.8	-	0	-	-77.8	-	0	-
Jt. No.	1333		1444		1341		1450	
LC-8	-58	-	0	-	-57.9	-	0	-
Jt. No.	1333		1445		1340		1479	
LC-9	-58.6	-	0	-	-58.7	-	0	-
Jt. No.	1335		1446		1341		1444	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surfa
S22B - Meridional Stress bottom surfa

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strengths, $f_c' = 3,2$ psi, as shown in Table 4-1 and Figure 4-10.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where t maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC and LC-10 are not critical.

Table 5-6 - Silo 3 - Summary of Maximum Stresses - Wall (Continued)

	(-210.7)		Meridional Stress (KSF)				(+49.1)	
	-S22T	%	+S22T	%	-S22B	%	+S22B	%
LC-1	-108	-	-1.56	-	-43.0	-	50.1	2
Jt. No	1333		1103		1147		1387	
LC-2	-94	-	-4.88	-	-40.5	-	49.4	0
Jt. No	1406		1103		1036		1387	
LC-3	-105	-	1.90	-	42.1	-	51.2	4
Jt. No	1406		1103		1110		1386	
LC-4	-72	-	-0.9	-	-31.9	-	37.8	-
Jt. No	1406		1103		1147		1387	
LC-6	84	-	-1.74	-	-42.2	-	35.5	-
Jt. No	1406		1103		1147		1387	
LC-7	-88	-	-5.1	-	-36	-	34.7	-
Jt. No	1406		1103		1184		1387	
LC-8	-64	-	-3.57	-	-36.5	-	26.2	-
Jt. No	1406		1103		1147		1387	
LC-9	-66	-	1.28	-	-31.4	-	27.2	-
Jt. No	1406		1103		1110		1386	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surface
S22B - Meridional Stress bottom surface

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3{,}250$ psi, as shown in Table 4-1 and Figure 4-10.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where the maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC-5 and LC-10 are not critical.

Table 5-7 - Silo 4 - Summary of Maximum Stresses - Dome

86.4

	(-93.6)		Hoop Stress (KSF)				(+14)	(24)
	-S11T	%	+S11T	%	-S11B	%	+S11B	f_s
LC-1	-72	-	-2.4	-	-74.6	-	27.3	10.86
Jt. No.	725		423		901		904	(3)
LC-2	-51	-	-1.9	-	-63	-	0	
Jt. No.	797		864		901		904	
LC-3	-66	-	2.07	-	-87	-	42.1	16.75
Jt. No.	790		40		901		904	(3)
LC-4	-45	-	-1.69	-	-76	-	21.2	8.43
Jt. No.	724		423		864		904	(3)
LC-6	-90	-	-2.4	-	-74.8	-	27.5	10.94
Jt. No.	724		423		901		904	(3)
LC-7	-68	-	-2.2	-	-63.3	-	0	
Jt. No.	725		864		901		725	
LC-8	-52	-	-1.1	-	-70.6	-	0	
Jt. No.	725		864		864		725	
LC-9	-72	-	-2.4	-	-102	-	27.3	10.86
Jt. No.	692		423		864		904	(3)

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surfa
S22B - Meridional Stress bottom surfa

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3,0$ psi, as shown in Table 4-1 and Figure 4-11.
2) % indicates overstress in concrete section.
3) f_s indicates stress in reinforcement (KSI).
4) Joint number shown in second row of each load case indicates approximate location where t maximum stress occurs.
5) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC and LC-10 are not critical.

Table 5-7 - Silo 4 - Summary of Maximum Stresses - Dome (Continued)

86.4

	(-93.6)		Meridional Stress (KSF)				(+14)	(24)
	-S22T	%	+S22T	%	-S22B	%	+S22B	f_s
LC-1	-50	-	9.1	-	-23	-	30	11.93
Jt. No.	727		734		937		790	(3)
LC-2	-42	-	2.4	-	-21.2	-	24	9.55
Jt. No.	855		939		937		692	(3)
LC-3	-65	-	18.1	1.29	-25.1	-	52	20.69
Jt. No.	855		734		937		860	(3)
LC-4	-37.5	-	7.1	-	-17.0	-	24	9.55
Jt. No.	692		734		937		856	(3)
LC-6	-50	-	9.2	-	-23	-	40	15.91
Jt. No.	692		734		937		860	(3)
LC-7	-38.5	-	2.49	-	-21.1	-	24	9.55
Jt. No.	692		939		937		692	(3)
LC-8	-27.5	-	2.12	-	-15.6	-	16.5	6.56
Jt. No.	692		939		937		692	(3)
LC-9	-60	-	9.09	-	-23	-	30	11.93
Jt. No.	692		734		937		790	(3)

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surface
S22B - Meridional Stress bottom surface

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3{,}000$ psi, as shown in Table 4-1 and Figure 4-11. Allowable stress in steel = 24 KSI.
2) % indicates overstress in concrete section.
3) f_s indicates stress in reinforcement (KSI).
4) Joint number shown in second row of each load case indicates approximate location where the maximum stress occurs.
5) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC-5 and LC-10 are not critical.

Table 5-8 - Silo 4 - Summary of Maximum Stresses - Wall

	(-210.7)		Hoop Stress (KSF)				(+49.1)	
	-S11T	%	+S11T	%	-S11B	%	+S11B	%
LC-1	-99.0	-	≃0	-	-99	-	≃0	-
Jt. No.	1333		1444		1341		1450	
LC-2	-99.0	-	≃0	-	-99	-	≃0	-
Jt. No.	1333		1444		1341		1450	
LC-3	-99	-	≃0	-	-99.5	-	≃0	-
Jt. No.	1335		1446		1341		1444	
LC-4	-73.9	-	≃0	-	-73.8	-	≃0	-
Jt. No.	1333		1445		1340		1479	
LC-6	-96	-	≃0	-	-95	-	≃0	-
Jt. No.	1333		1444		1339		1480	
LC-7	-96	-	≃0	-	-95	-	≃0	-
Jt. No.	1333		1444		1339		1480	
LC-8	-71	-	≃0	-	-70.9	-	≃0	-
Jt. No.	1333		1445		1338		1479	
LC-9	-72.2	-	≃0	-	-71.6	-	≃0	-
Jt. No.	1334		1445		1339		1480	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surf
S22B - Meridional Stress bottom surf

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3,$ psi, as shown in Table 4-1 and Figure 4-11.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects L(and LC-10 are not critical.

Table 5-8 - Silo 4 - Summary of Maximum Stresses - Wall (Continued)

	(-210.7)		Meridional Stress (KSF)				(+49.1)	
	-S22T	%	+S22T	%	-S22B	%	+S22B	%
LC-1	-96	-	-1.98	-	-40	-	49.8	1
Jt. No	1406		1103		1110		1387	
LC-2	-99	-	-5.25	-	-44	-	49.0	-
Jt. No	1406		1103		1110		1387	
LC-3	-105	-	1.42	-	-41.6	-	50.8	3
Jt. No	1406		1103		1110		1386	
LC-4	-72	-	-1.25	-	-30	-	37.5	-
Jt. No	1406		1103		1147		1387	
LC-6	-96	-	-1.8	-	-43.4	-	43.4	-
Jt. No	1370		1103		1074		1370	
LC-7	-88	-	-5.1	-	-44	-	42.6	-
Jt. No	1370		1103		1110		1370	
LC-8	-72	-	-3.56	-	-30	-	32.2	-
Jt. No	1370		1103		1110		1370	
LC-9	-66	-	1.2	-	-31.3	-	33.3	-
Jt. No	1370		1103		1110		1370	

S11T - Hoop Stress top surface
S11B - Hoop Stress bottom surface
S22T - Meridional Stress top surface
S22B - Meridional Stress bottom surface

Notes:

1) Allowable stresses in concrete (shown in parenthesis) are based on concrete strength, $f_c' = 3{,}250$ psi, as shown in Table 4-1 and Figure 4-11.
2) % indicates overstress in concrete section.
3) Joint number shown in second row of each load case indicates approximate location where the maximum stress occurs.
4) LC: Load combination (see Subsection 4.3). Load combinations with temperature effects LC-5 and LC-10 are not critical.

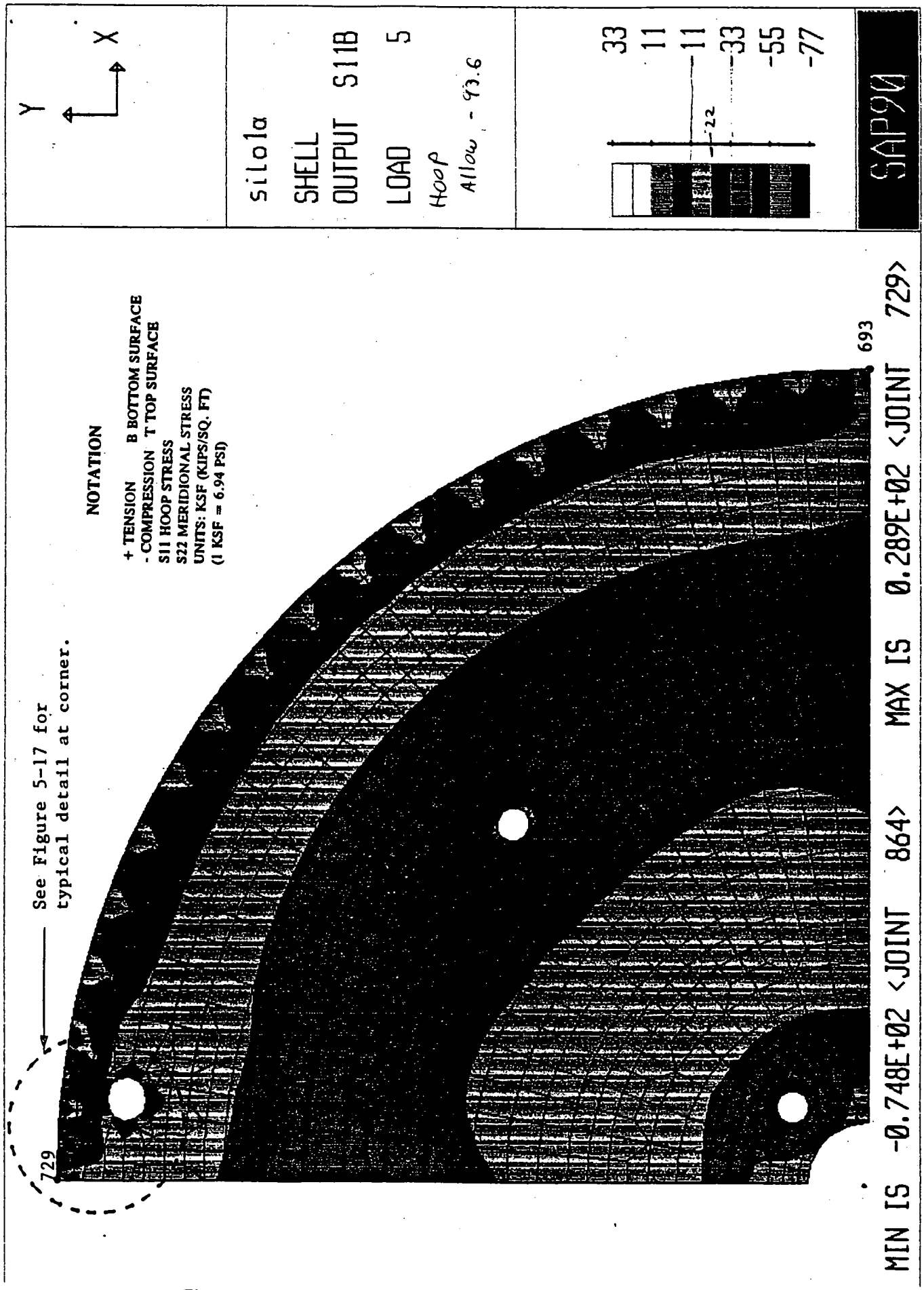


Figure 5-1 - Hoop Stress S11B for Silo 1 Dome, LC=5 (DL+LL+CL)

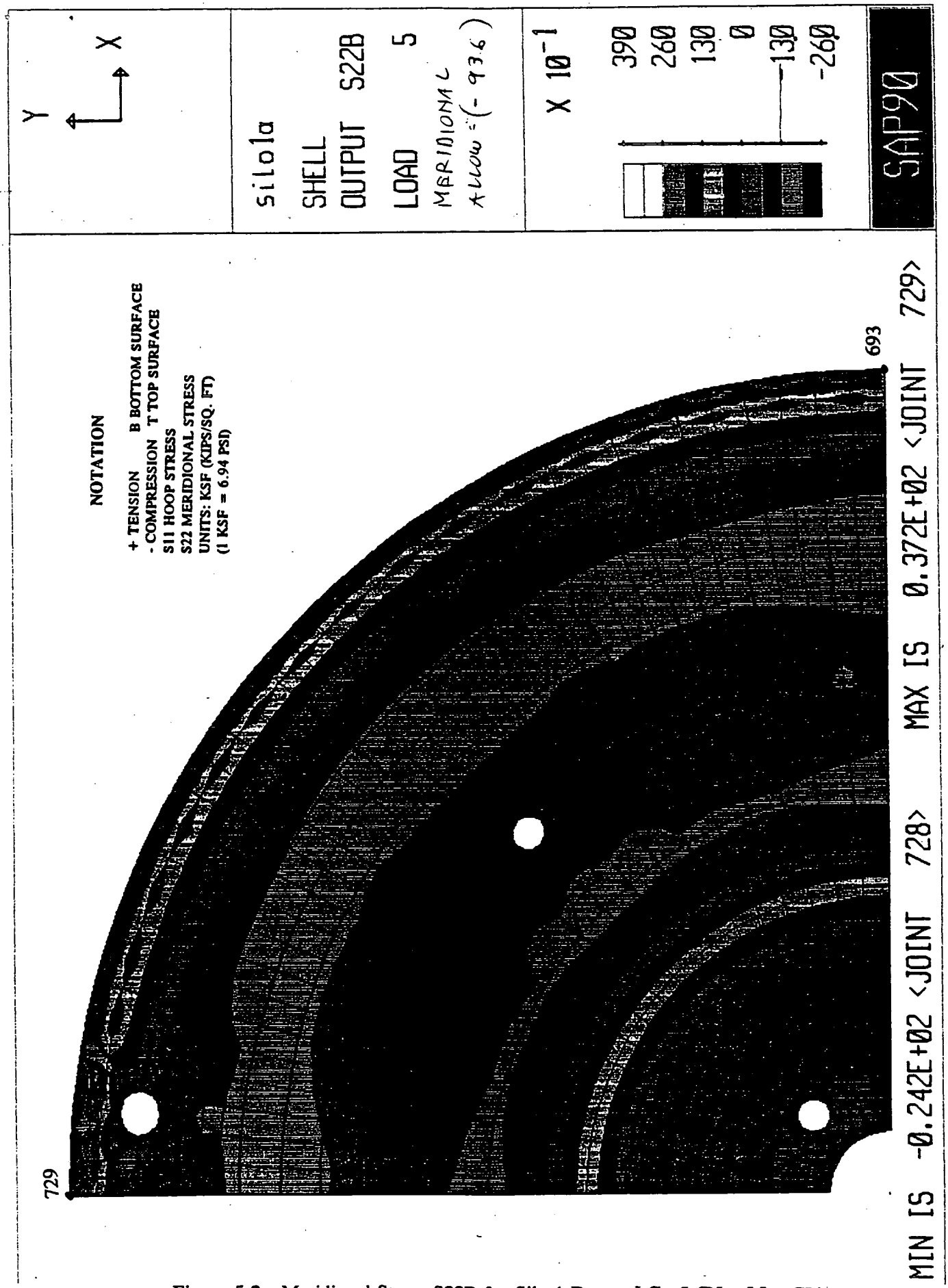


Figure 5-2 - Meridional Stress S22B for Silo 1 Dome, LC=5 (DL+LL+CL)

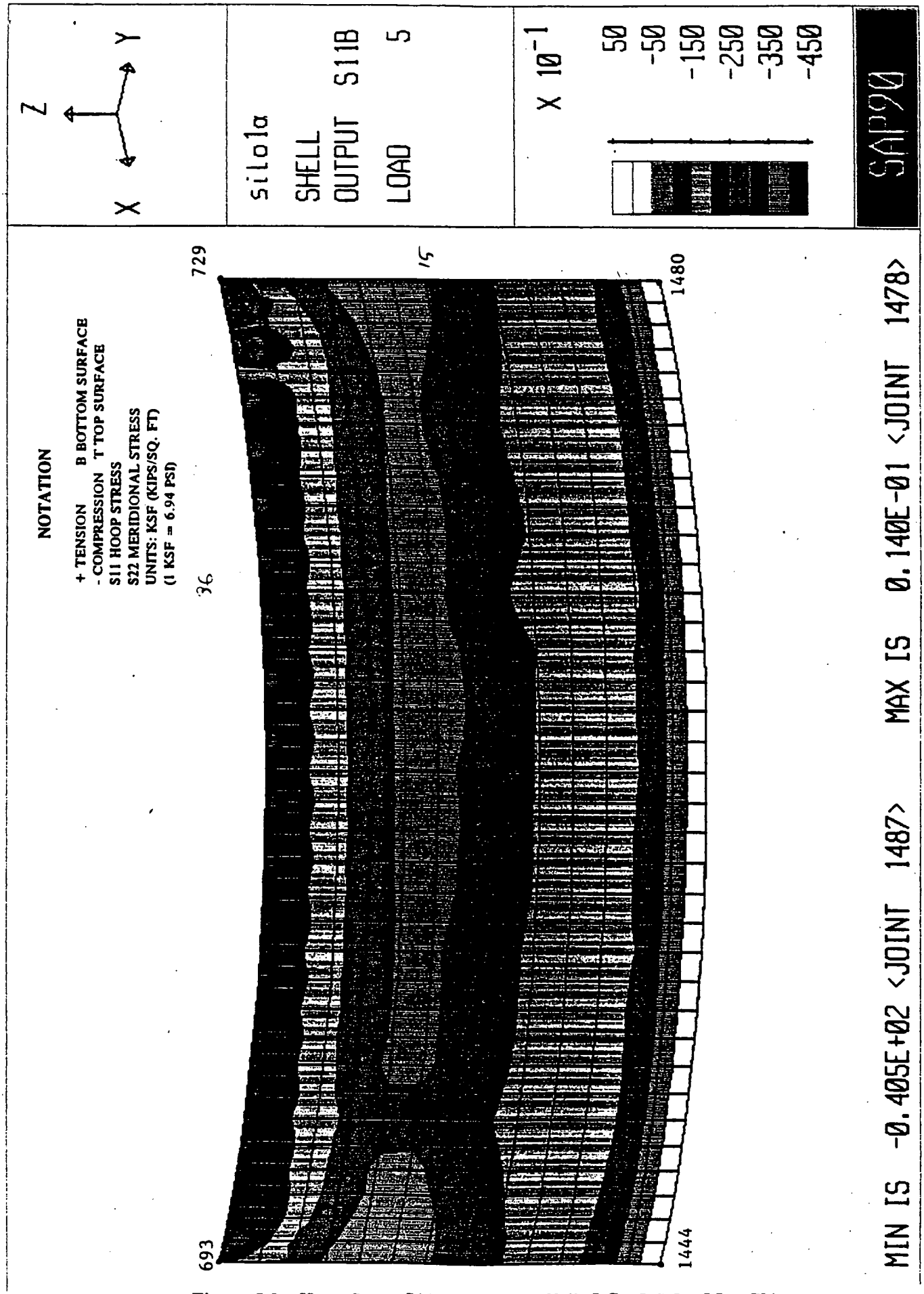


Figure 5-3 - Hoop Stress S11B for Silo 1 Wall, LC=5 (DL+LL+CL)

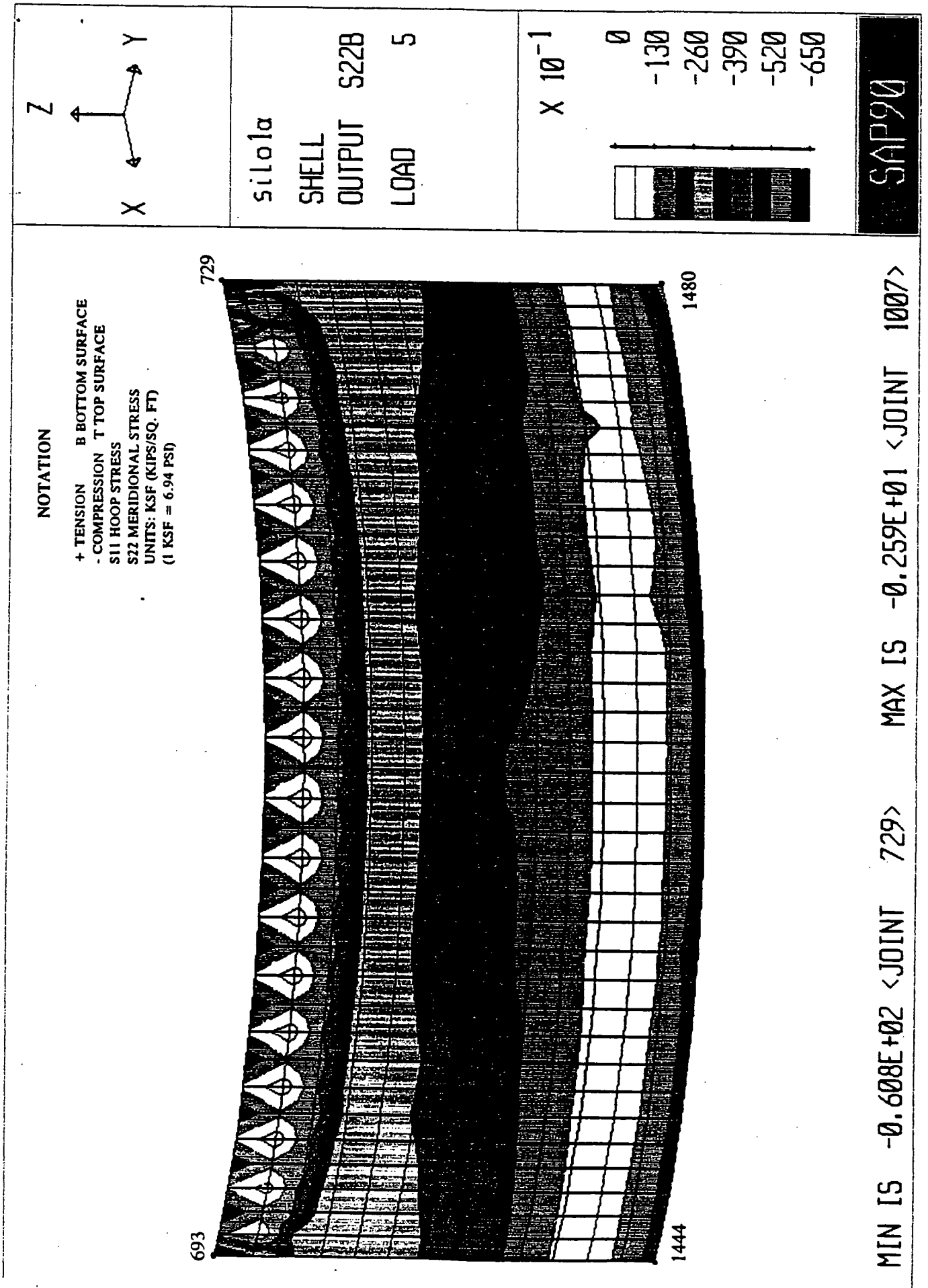


Figure 5-4 - Meridional Stress S22B for Silo 1 Wall, LC=5 (DL+LL+CL)

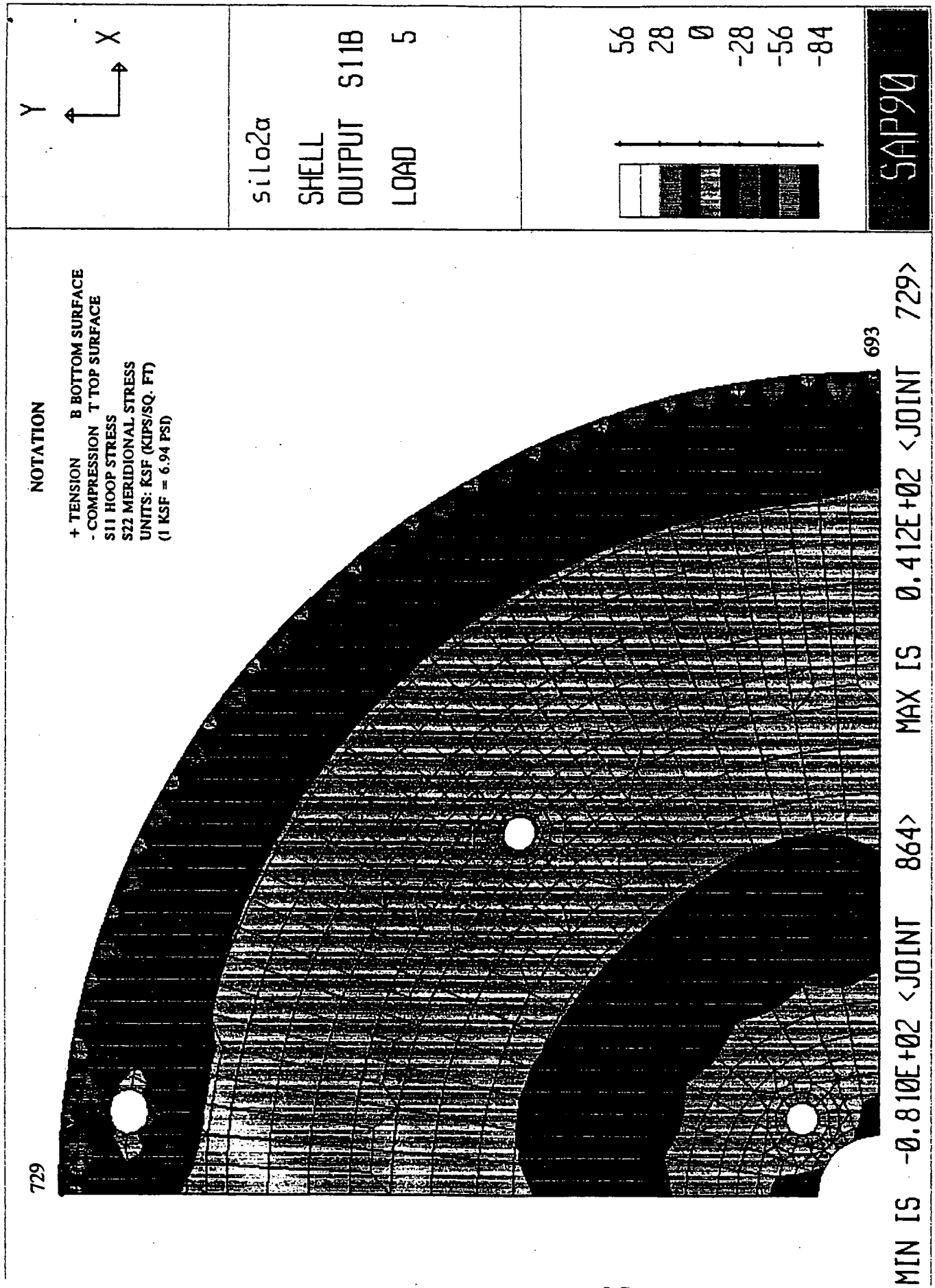


Figure 5-5 - Hoop Stress S11B for Silo 2 Dome, LC=5 (DL+LL+CL)

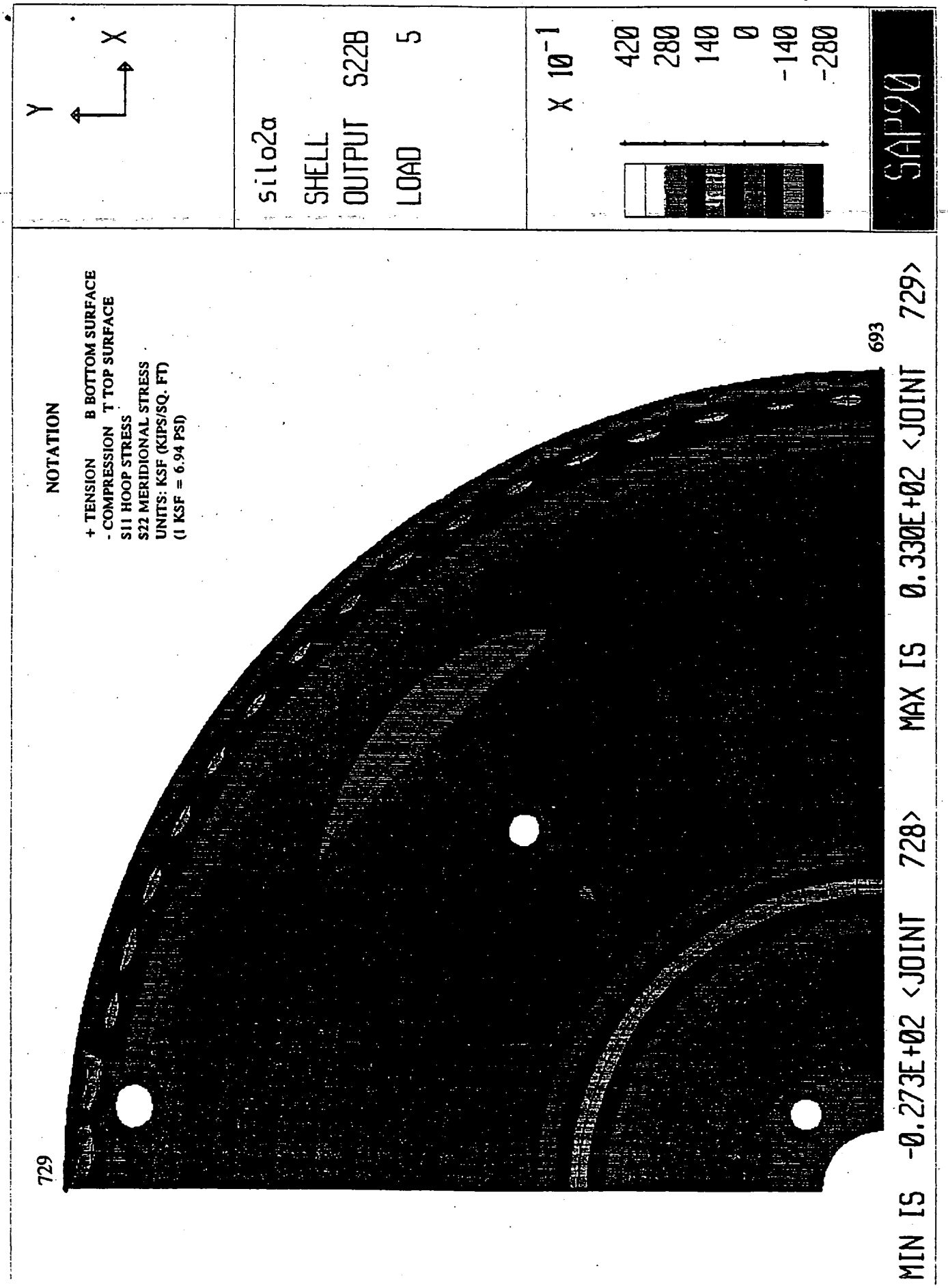


Figure 5-6 - Meridional Stress S22B for Silo 2 Dome, LC=5 (DL+LL+CL)

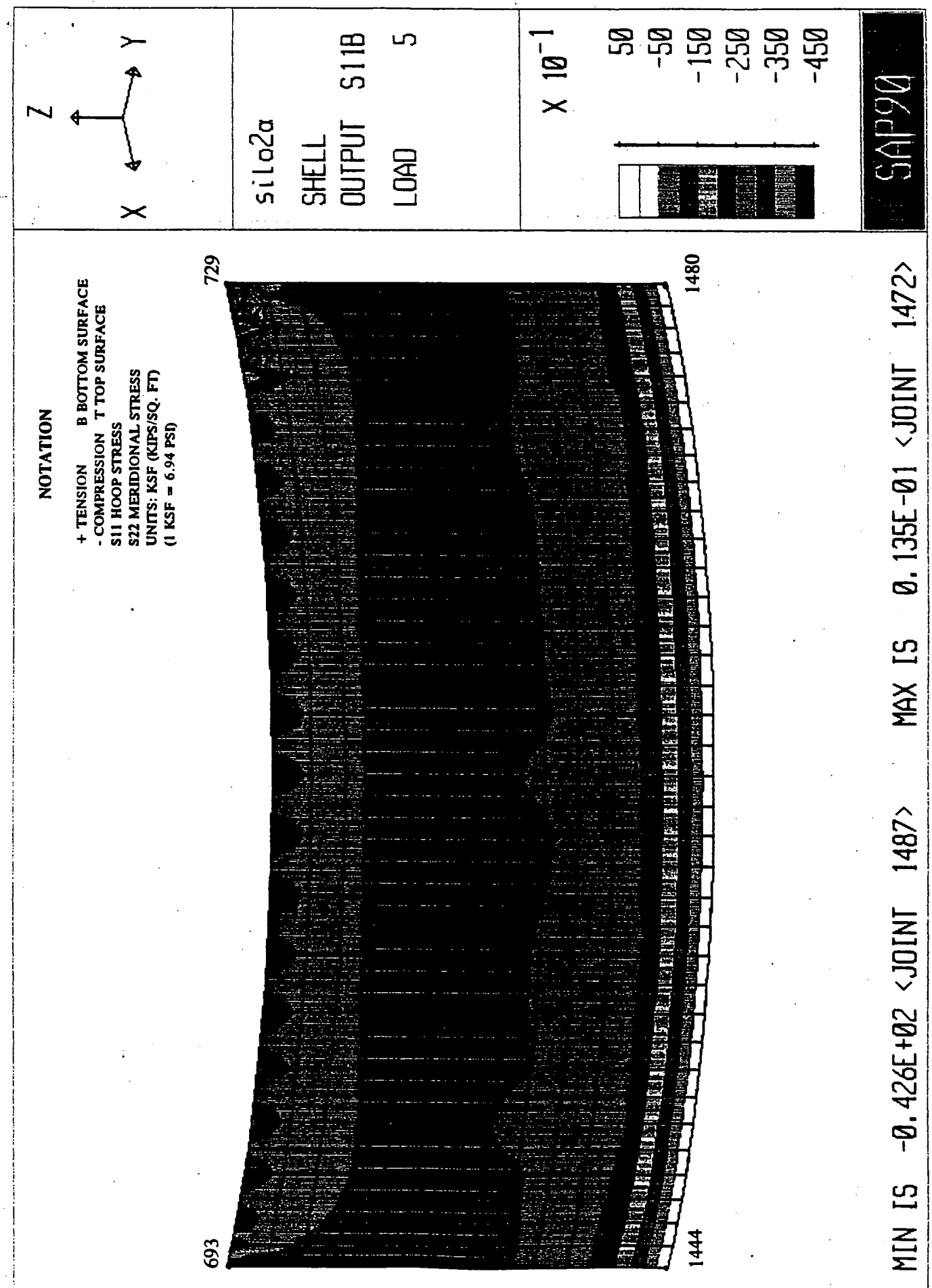


Figure 5-7 - Hoop Stress S11B for Silo 2 Wall, LC=5 (DL+LL+CL)

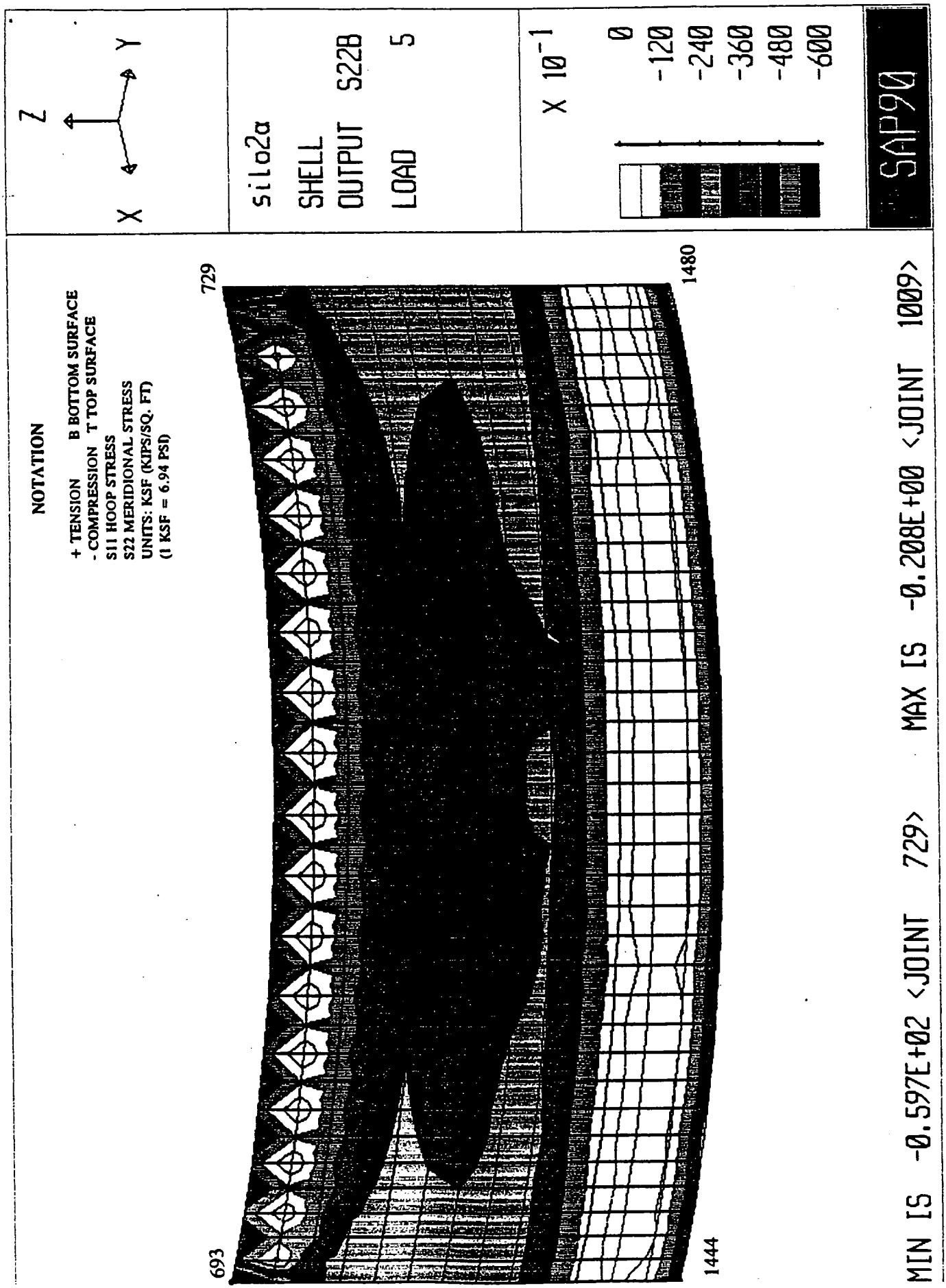


Figure 5-8 - Meridional Stress S22B for Silo 2 Wall, LC=5 (DL+LL+CL)

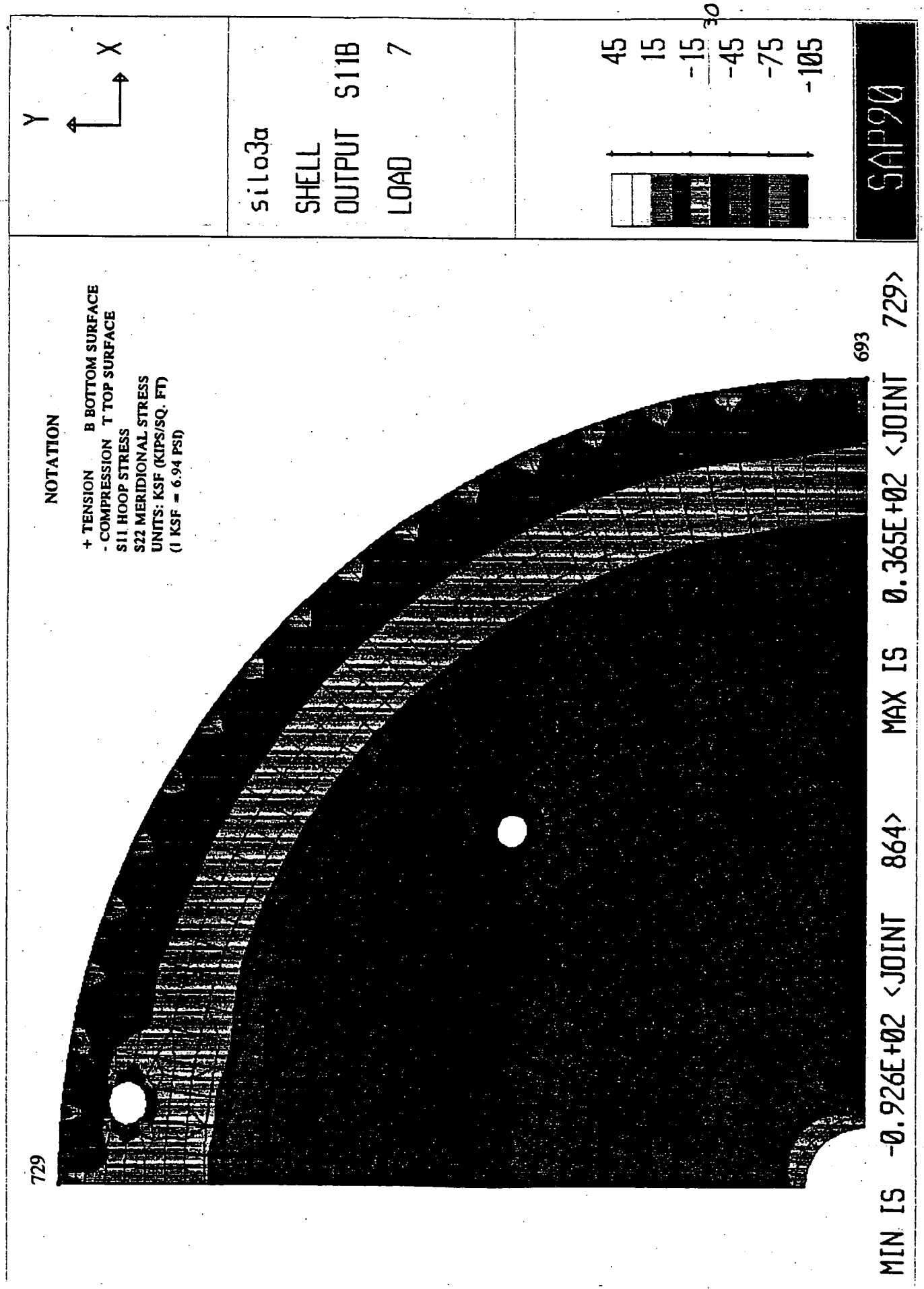


Figure 5-9 - Hoop Stress S11B for Silo 3 Dome, LC=7 (DL+LL+CL)

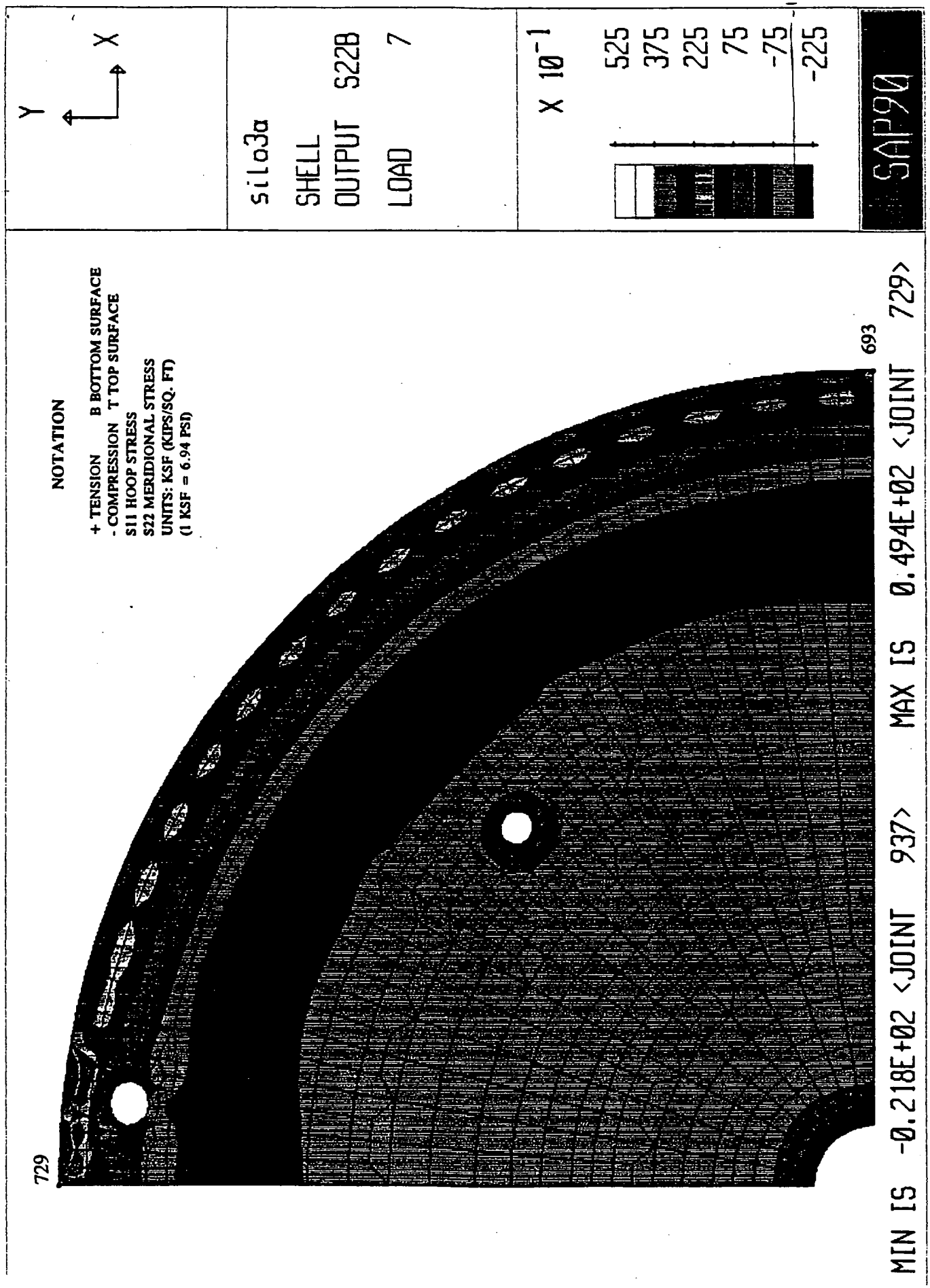


Figure 5-10 - Meridional Stress S22B for Silo 3 Dome, LC=7 (DL+LL+CL)

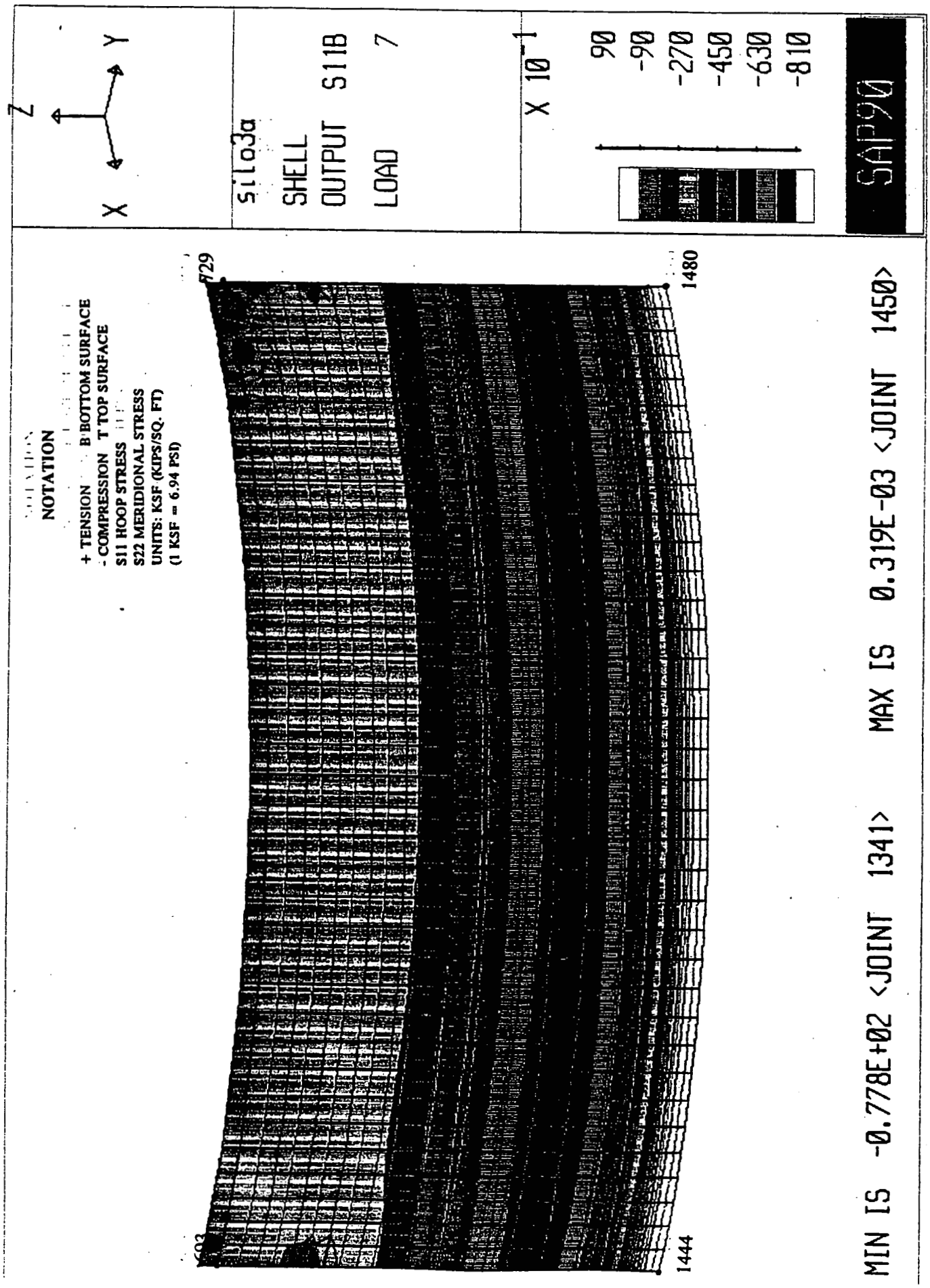


Figure 5-11 - Hoop Stress S11B for Silo 3 Wall, LC=7 (DL+LL+CL)

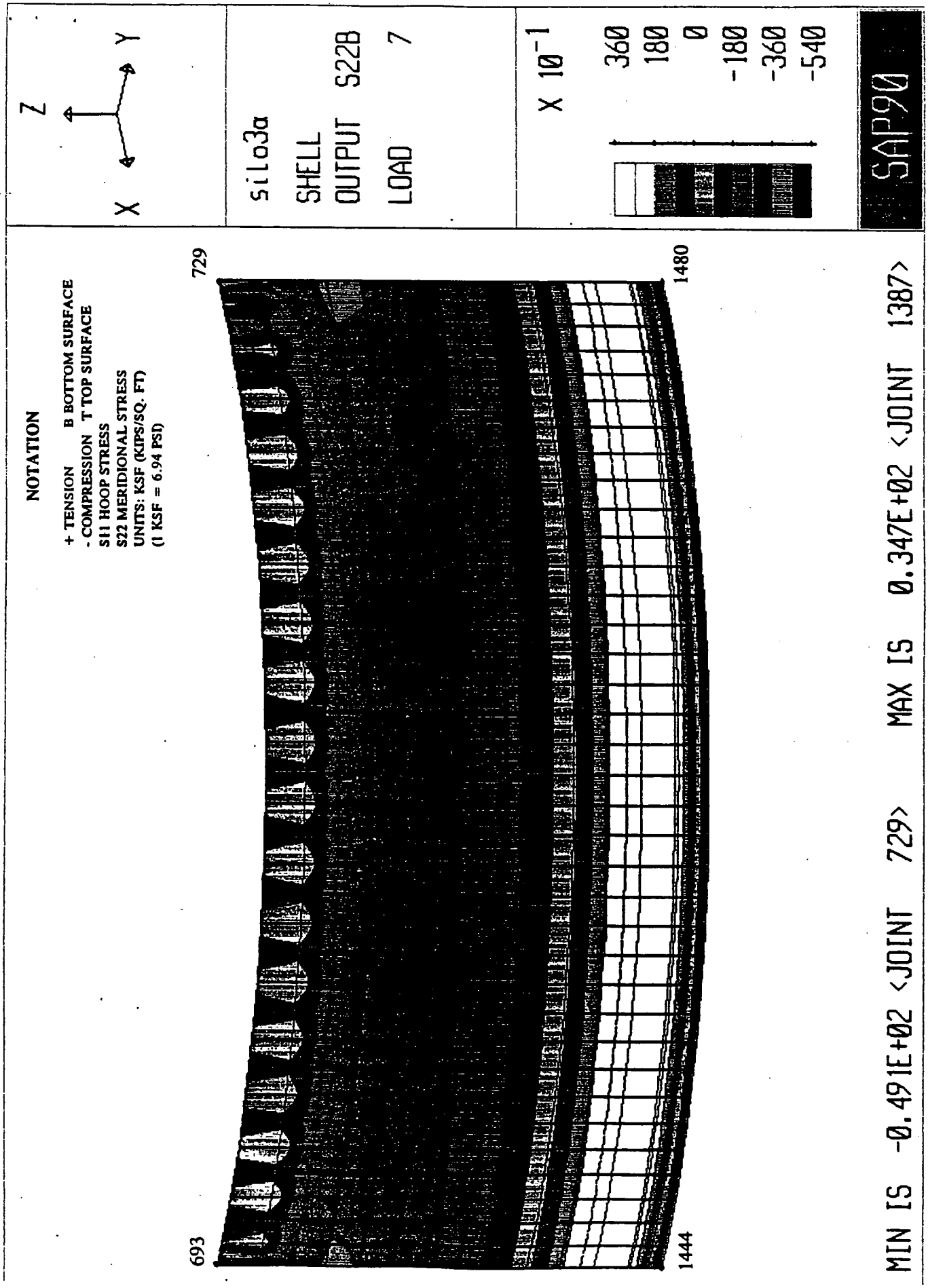


Figure 5-12 - Meridional Stress S22B for Silo 3 Wall, LC=7 (DL+LL+CL)

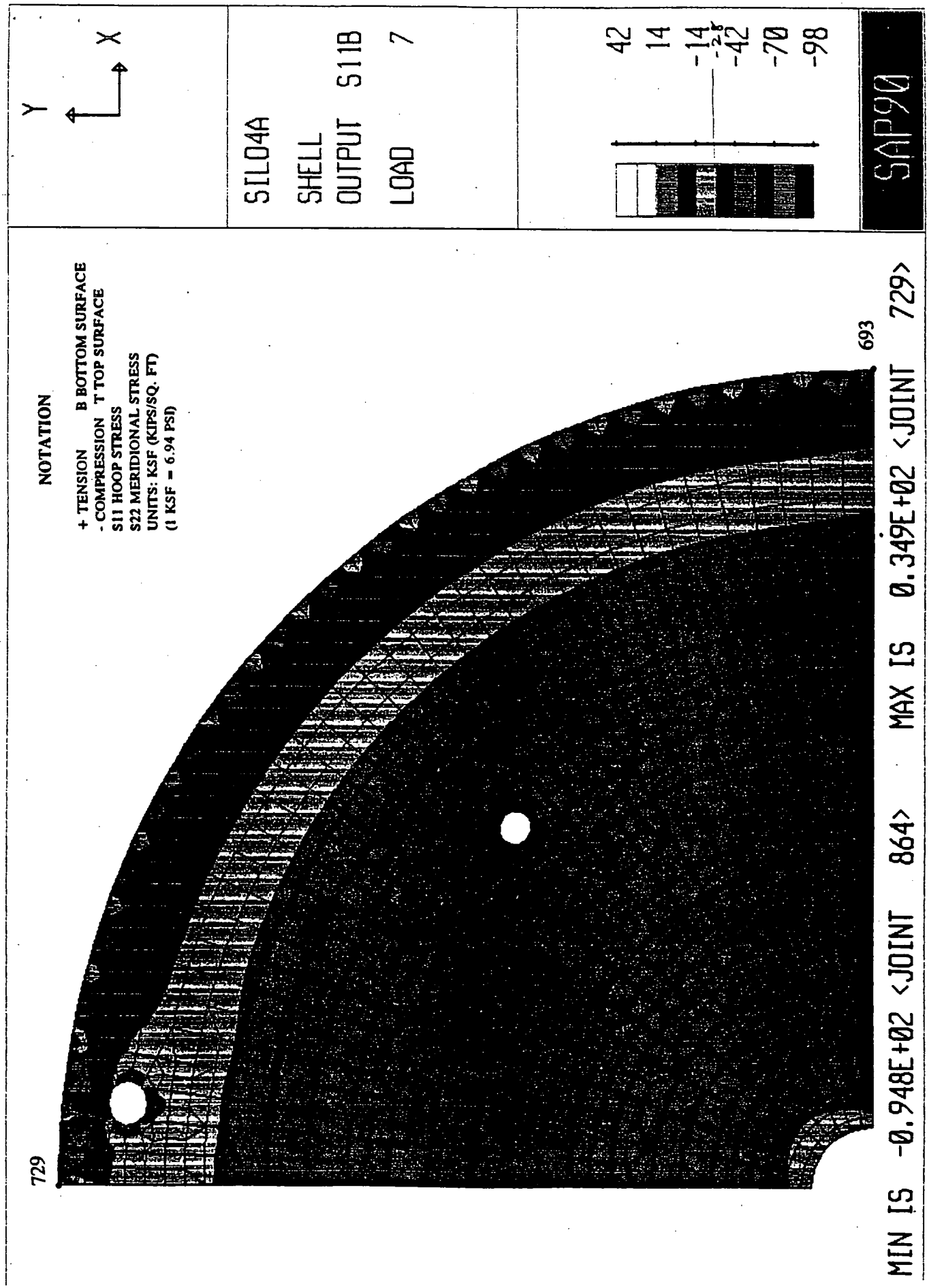


Figure 5-13 - Hoop Stress S11B for Silo 4 Dome, LC=7 (DL+LL+CL)

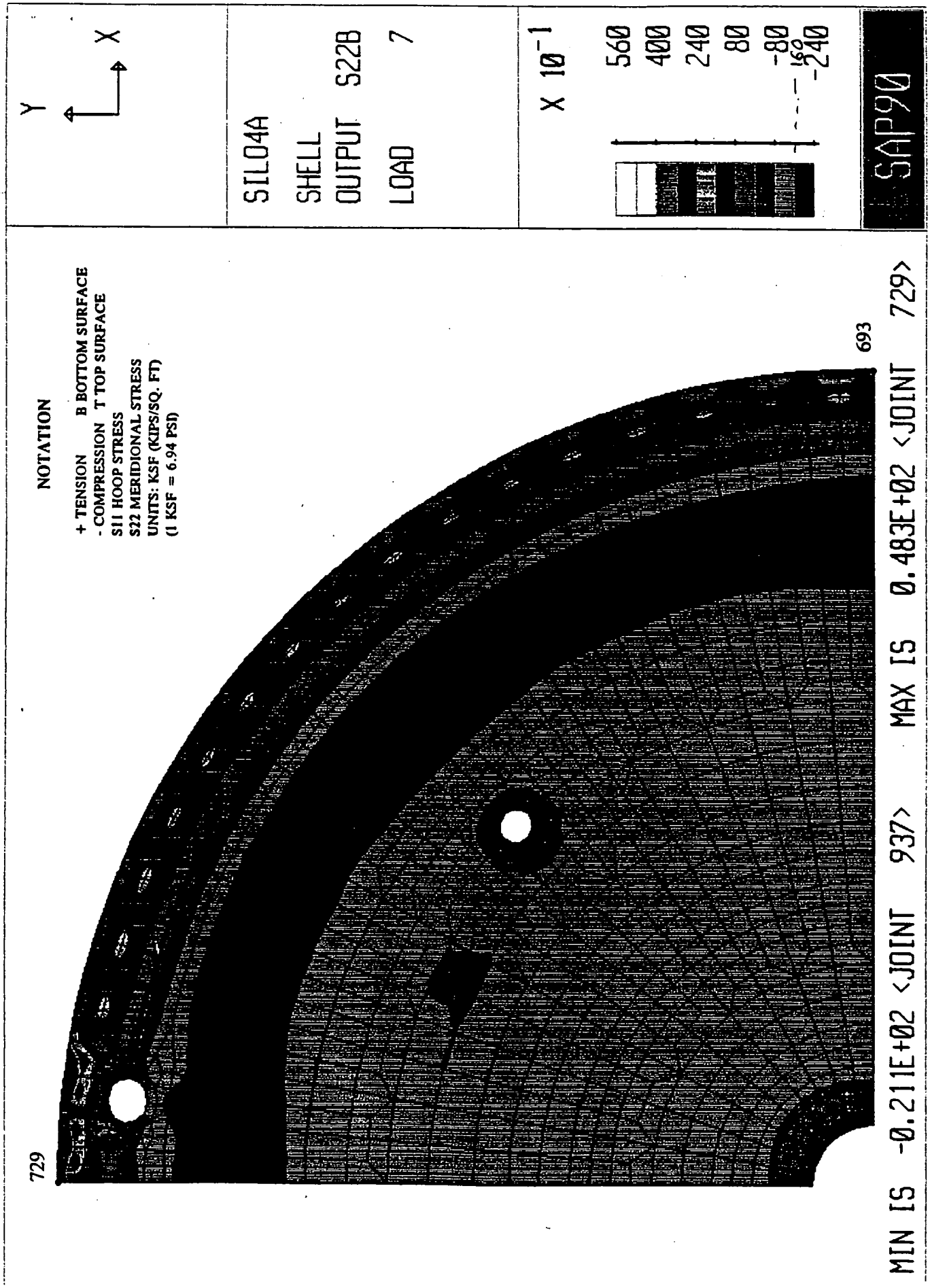


Figure 5-14 - Meridional Stress S22B for Silo 4 Dome, LC=7 (DL+LL+CL)

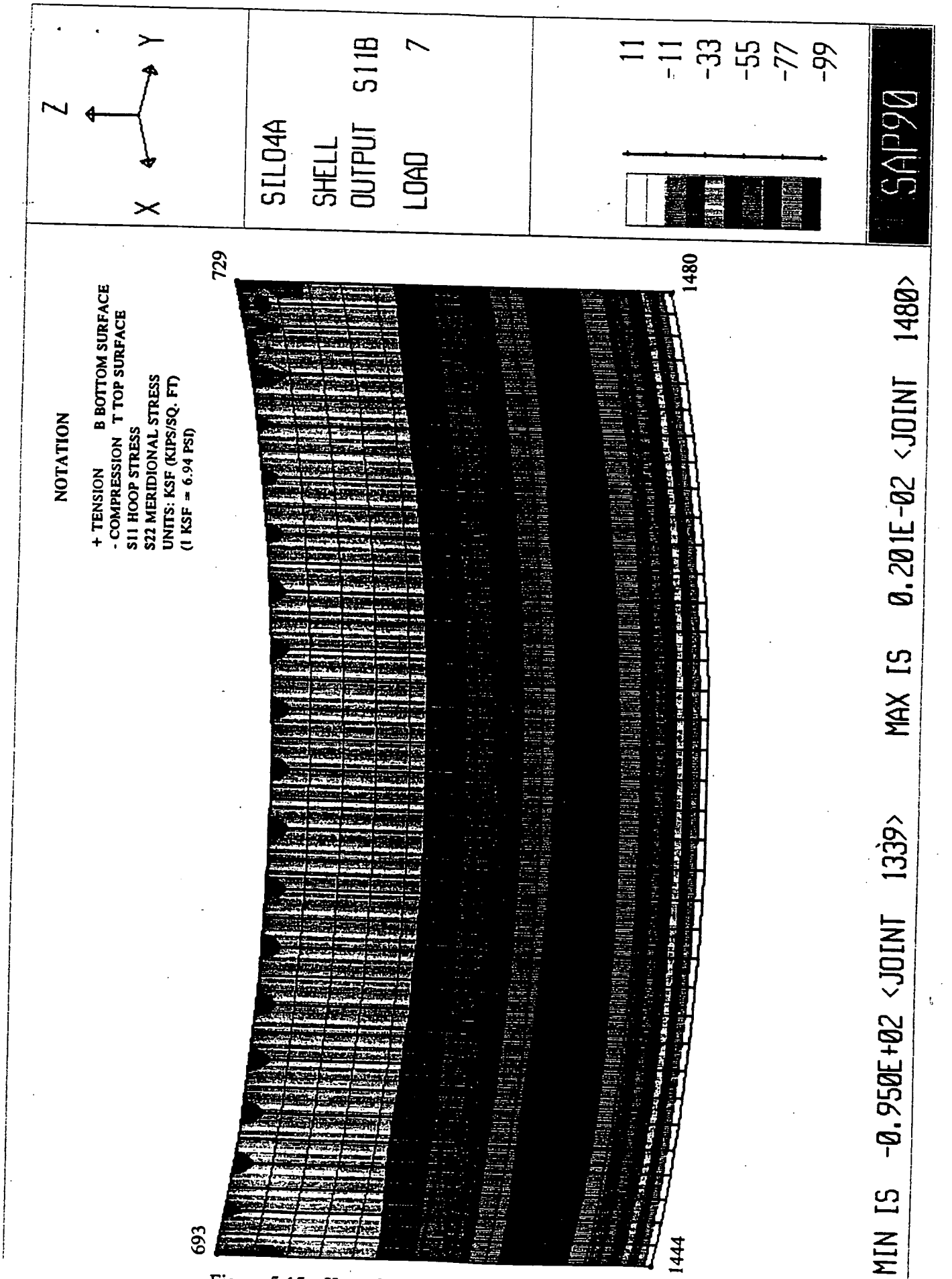


Figure 5-15 - Hoop Stress S11B for Silo 4 Wall, LC=7 (DL+LL+CL)

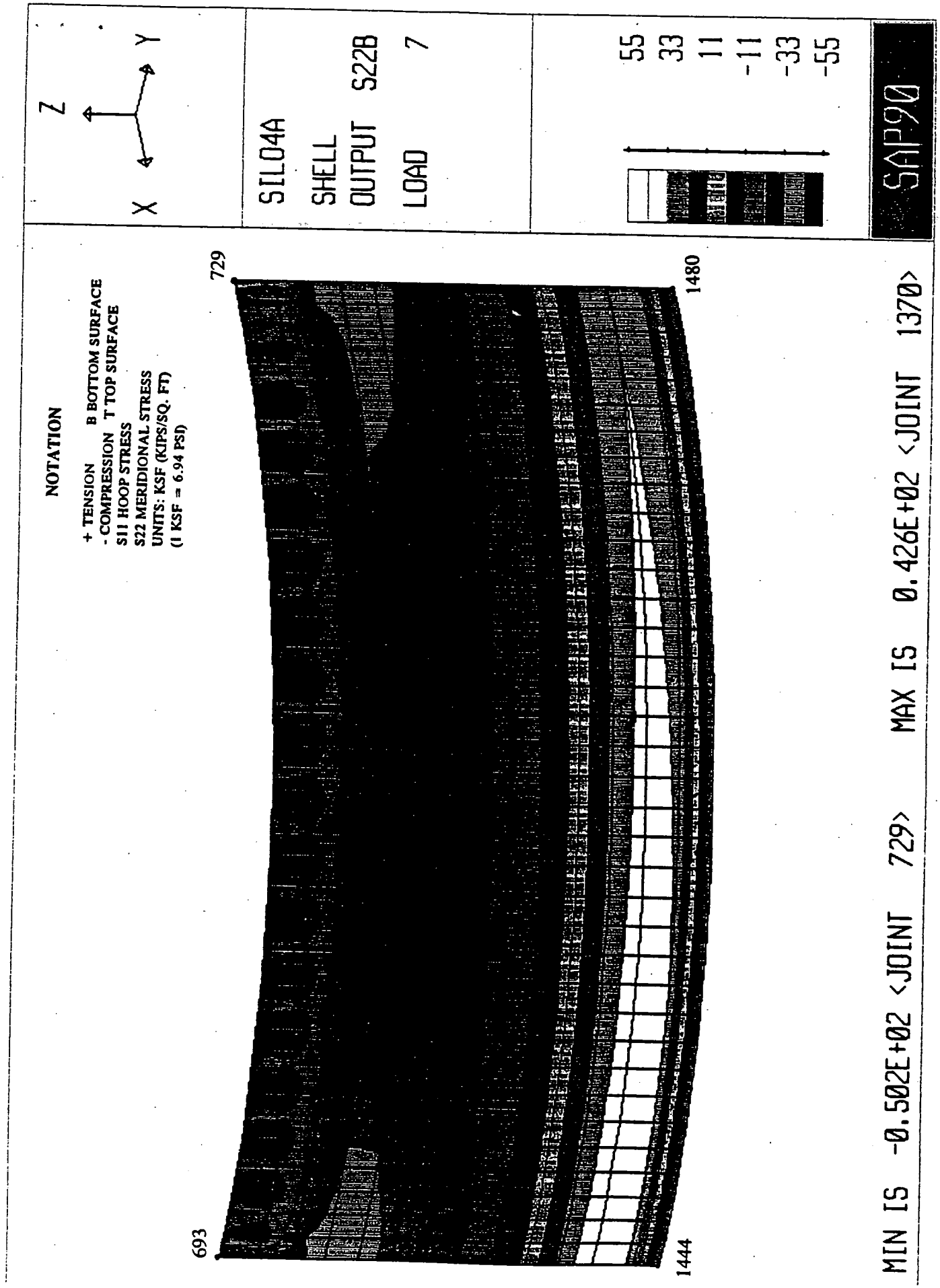


Figure 5-16 - Meridional Stress S22B for Silo 4 Wall, LC=7 (DL+LL+CL)

For any given stress component,stress contour plots were obtained from SAPLOT post processor and examined to determine the maximum +ve and -ve values. Due to possible limitations of the quarter model the unrealistic peak values obtained at the corner nodes (729 and 693) were omitted. Figure 5-17 shows a typical stress contour obtained for the enlarged area near the dome wall intersection near node 729.

The stress contours at suspicious areas were enlarged by similar stress contour plots to determine the true maximum values. The results were also verified by comparing numerical values from SAP90 stress output files.

To determine the out-of-plane shear stresses separate computer runs were made to obtain the out-of-plane shear force output. These results were then reviewed to determine the maximum values.
The shear stress values were not critical for any silo.

5.2 Summary of Displacements

The maximum displacements were obtained for each load case for each silo. The results are summarized in Tables 5-9, 5-10, 5-11, and 5-12 for Silos 1, 2, 3, and 4, respectively. Figure 5-18 shows a typical deformed shape for Silo 2 for Load Case 5.

5.3 SAP90 Files

Table 5-13 shows the list of SAP90 computer input and output files for Silos 1, 2, 3, and 4, including a brief description of each file.

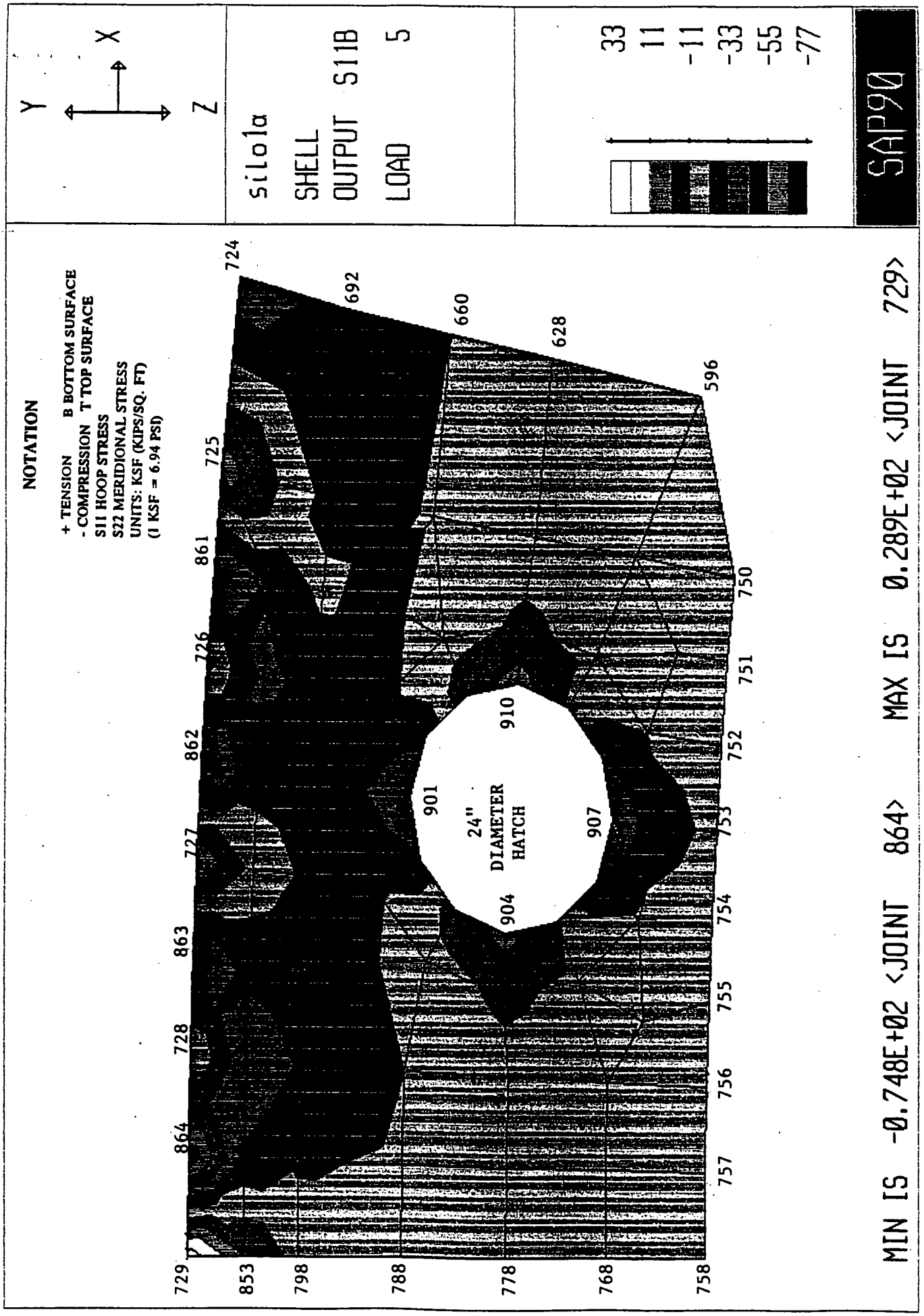


Figure 5-17 - Meridional Stress S11B for Silo 1 Dome Wall Intersection, LC=5 (DL+LL+CL)

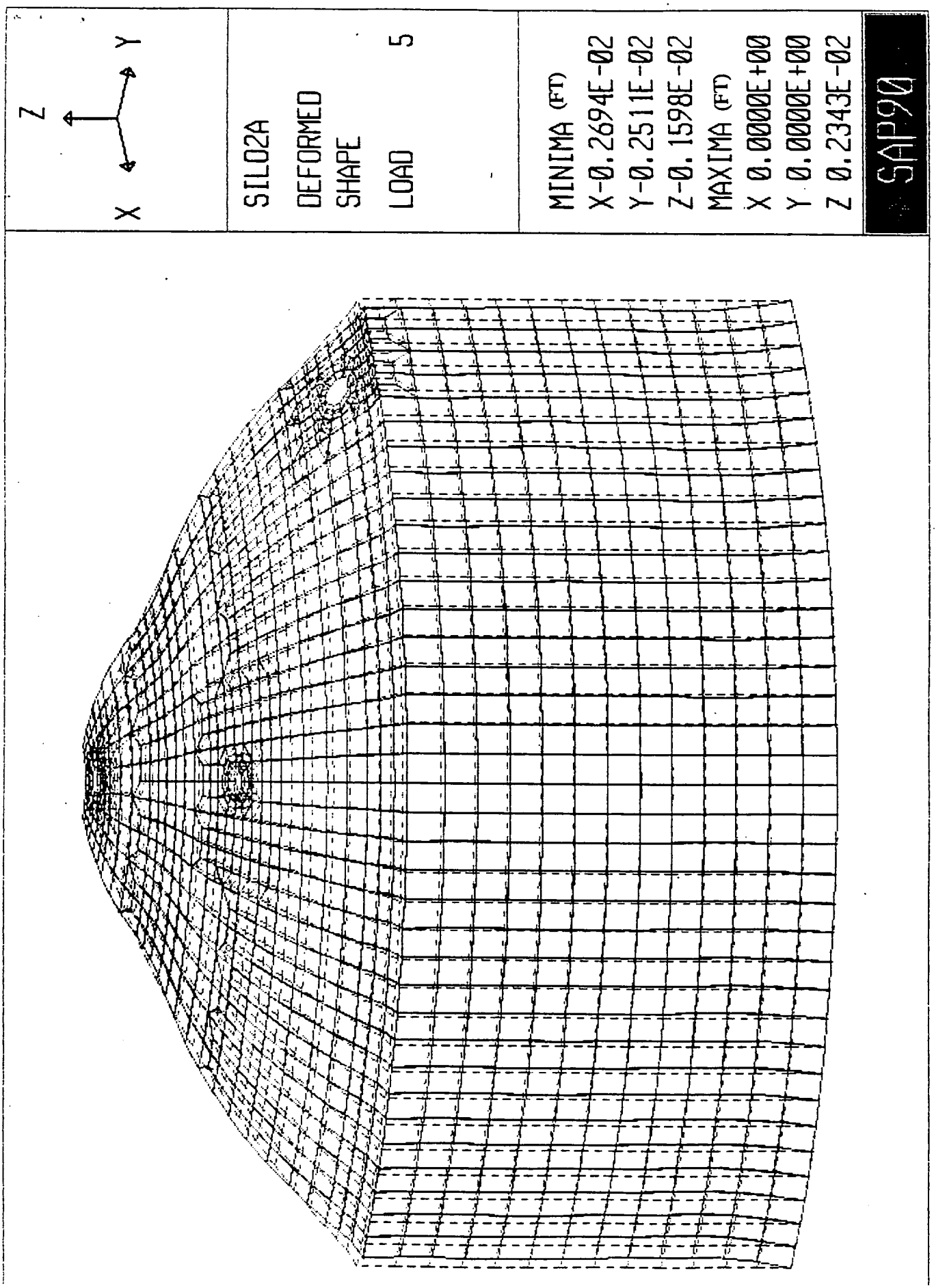


Figure 5-18 - Magnified Deformed Shape of Silo 2 for Load Case 5 (DL+LL+CL)

Table 5-10 - Silo 2 - Summary of Maximum Displacements

		+X	+Y	+Z	MF	-X	-Y	-Z	MF
LC-1	ft.	0	0	.447	10^{-2}	.148	.147	.0147	10^{-1}
	in.			.054		.178	.176	.017	
LC-2	ft.	0	0	.3041	10^{-2}	.148	.147	.0151	10^{-1}
	in.			.036		.178	.176	.018	
LC-3	ft.	0	0	.3459	10^{-2}	.1099	.1088	.0109	10^{-1}
	in.			.042		.132	.131	.013	
LC-4	ft.	0	0	.4049	10^{-2}	.2775	.2827	.1466	10^{-2}
	in.			.049		.033	.034	0.018	
LC-5	ft.	0	0	.2655	10^{-2}	.2131	.2156	.1507	10^{-2}
	in.			.032		.026	.026	.018	
LC-7	ft.	0	0	.2085	10^{-2}	.1564	.1583	.1125	10^{-2}
	in.			.025		.019	.019	.014	

MF: Multiplication Factor

Table 5-12 - Silo 4 - Summary of Maximum Displacements

		+X	+Y	+Z	MF	-X	-Y	-Z	MF
LC-1	ft.			.6396	10^{-2}	.866	.8495	.1506	10^{-2}
	in.			.0768		.1039	.1019	.0182	
LC-2	ft.			.4449	10^{-2}	.866	.8497	.1548	10^{-2}
	in.			.0533		.1039	.1019	.0182	
LC-3	ft.			.8519	10^{-2}	.8702	.8444	.146	10^{-2}
	in.			.1022		.1044	.1013	.0175	
LC-4	ft.			.4876	10^{-2}	.6435	.631	.1127	10^{-2}
	in.			.0585		.0772	.0757	.0135	
LC-6	ft.			.6405	10^{-2}	.8427	.7829	.1503	10^{-2}
	in.			.0769		.1011	.0939	.018	
LC-7	ft.			.4455	10^{-2}	.8426	.7835	.1544	10^{-2}
	in.			.0535		.1011	.094	.0185	
LC-8	ft.			.3419	10^{-2}	.6259	.58	.1156	10^{-2}
	in.			.0378		.0751	.0696	.0139	
LC-9	ft.		.0041	.6396	10^{-2}	.6351	.5820	.1093	10^{-2}
	in.		0	.0768		.0762	.0698	.013	

MF: Multiplication Factor

6) The shear stresses in the dome and walls are within allowable stresses for Silos 1, 2, 3, anc

7) The maximum displacements in the X, Y, and Z directions are less than 0.25 inches for Silc 2, 3, and 4.

6.2 Path Forward

1) Establish the structural condition of the silos as they exist now, including the material prope: and material thicknesses by conducting independent NDT tests on each silo as planned und separate project order (PO-76).

2) Evaluate the new test results to determine if the results from the 1986 test results are applicable.

3) Evaluate the new test results to determine if there are any major concerns about the struct integrity of the silos.

4) Determine the future course of action based on the evaluation of the new test results.

6.3 Conclusion

1) Based on the results of structural analyses performed to date and the assumptions made in report, including original design criteria, the structural integrity of Silos 1,2,3, and 4 should be affected by the proposed 6-foot diameter opening at the center of the dome, subject to loading restriction that Silos 1 and 2 not be empty with the embankment in place. The find of this report need to be confirmed by independent NDT results.

(DOE 1989) United States Department of Energy, April 6, 1989. *General Design Criteria* DOE Order 6430.1A.

(FERMCO 1993) Fernald Environmental Restoration Management Corporation, 1993. Memo from D. Nixon to B. Vogel with Attachment 1 Containing Seven Letters from NLO.

(McGraw Hill 1965) McGraw Hill, 1965. *Thin Shell Concrete Structures*, Billington, D.P.

(Muenow and Associates 1985a) Muenow and Associates, Inc., November 3 to 9, 1855. *K-65 Silos Study and Evaluation for NLO, Inc.*

(Muneow and Associates 1985b) ———, November 3 to 9, 1985. *Non-Destructive Evaluation of K-65 Tanks Numbered Three and Four*, NLO Facility.

(Nawy 1989) Nawy, E.G., 1989. *Prestressed Concrete - A Fundamental Approach.*

(Nutting 1993) H.C. Nutting, 1993. *Report of Geotechnical Investigation Surrounding Silos 1-* Pilot Plant Vitrification Facility, Fernald, Ohio.

(OBBC) Ohio Basic Building Code, 1991. OBBC 91.

(PARSONS 1991) PARSONS ERA Project, 1991. *Silos 1 and 2 Facility Safety Analysis Report*

(PARSONS 1992) ———, 1992. OU-4 Report, *Remedial Action Conceptual Design Report*, Volumes I and II.

(PARSONS 1993a) ———, May 1993. *Design Criteria Package for the CRU-4 Vitrification Projects*, Revision A.

(PARSONS 1993b) ———, May 1993. *Project Order Plan for PO-92*, Revision 1.

(PCI a) Precast and Prestressed Concrete, *PCI Design Handbook.*

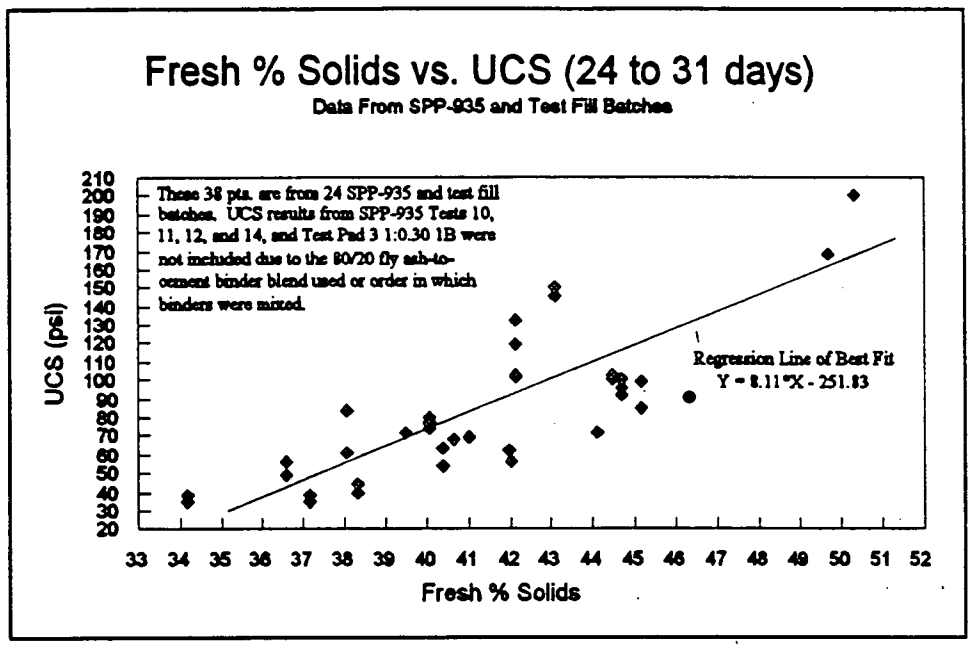
(PCI b) Precast and Prestressed Concrete, *PCI Design Handbook*, Third Edition.

(Preload a) Preload Enterprises, Inc. Drawing 5IT29-2 - Two 125,000 CF Tanks.

(Preload b) ———. Drawing 3035-Sketch 1, Roof Openings, Metal Oxide Tanks.

Figure 5-1 presents unit weight data of CSS grout, measured immediately after mixing, plotted against respective long-term (24 to 31 days) UCS results. Based on this comparison, unit weight used as an indirect measure of solids content of thickened sludge and CSS grout will be a quality control parameter measured during CSS Production Facility operation.

Figure 5-1



5.3 TCLP Results

The results of CSSX-SPP-935 *Optimization Tests for CSS Grout-Like Product* (Appendix N) indicate flocculated sludge, oversized material (>0.125 in.) from dredged sludge slurry, grout product, and free liquids (from the grout) passed the TCLP test for TC regulatory levels. In addition, the results of CSSX-SPP-930, *Grout Weathering Test* (Appendix O) indicate that CSS grout TCLP results do not significantly change due to weathering for tested recipes of 1:0.2 and 1:0.3 sludge-to-binder ratios.

ATTACHMENT 2 2 4

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Actual Waste Loadings of Solidified Silo 3 Wastes and TCLP Comparisons

a Test #	b Weight Silo 3 Material (g)	c Binder (g)	d Water Added (g)	e Treated Waste Weight (g)	f Silo 3 Material Dry Weight (g)	g **Actual Waste Loading f/e x 100 wt%**	h Calculated Cr TCLP From Dilution Only, ppm	i Actual Cr TCLP From Treatment, ppm
initial	na	na	na	na	na	**na**	6.1	na
1	400	600	425	1425	380	**26.67**	1.7	1.3
2	500	500	445	1445	475	**32.87**	2.1	1.5
3	600	400	470	1470	570	**38.78**	2.5	1.8
4	700	300	475	1475	665	**45.08**	2.9	2.3
5	500	500	1000	2000	475	**23.75**	1.5	***1.5***
6	600	400	950	1950	570	**29.23**	1.9	1.8
30/70 7	700	300	875	1875	665	**35.47**	2.3	***2.4***
80/20 8	800	200	825	1825	760	**41.64**	2.7	***2.7***
9	400	600	500	1500	380	**25.33**	1.6	0.6
10	400	400	370	1170	380	**32.48**	2.1	0.8
11	400	267	325	992	380	**38.31**	2.5	0.7
12	500	214	375	1089	475	**43.62**	2.8	0.9
13	400	400	850	1650	380	**23.03**	1.5	0.4
14	400	267	625	1292	380	**29.41**	1.9	0.7
15	400	171	525	1096	380	**34.67**	2.2	0.4
16	500	125	400	1025	475	**46.34**	3.0	0.3
Cement Proving	591.9	394.6	500	1487	562	**37.83**	2.4	not available
Aquaset Proving	591.9	591.9	1150	2334	562	**24.09**	1.5	not available

italics means that the TCLP results are not as good as dilution; however, all tests without pretreatment are close.

Alt 2 in '97 dollars

ESTIMATE SUMMARY SHEET

Vit.Silos1,2, CementSilo3Alt.2 6MT/day 3 Trains(VitrificationFacility)

ESTIMATE NO.: C4-96-12-01

CLIENT: DOE

WBS NO.: 1.1.1.1.4.1.4.1

FERMCO

DATE: 07-Jan-97

ESTIMATOR: Irvine/Clatt

LOCATION: FERNALD

TASK NO.: 4CBAC

ITEM DESCRIPTION	M/H	RATE	LABOR $	S/C $	MAT'L $	EQUIP. $	TOTAL $
Civil & Excavation All Facilities	9,860		$188,300	$0	$84,000	$0	$272,300
Concrete All Facilities	148,980		$2,996,000	$0	$2,168,000	$0	$5,164,000
Structural Steel- All Facilities	37,210		$807,800	$0	$1,052,000	$0	$1,859,800
Architectural/Buildings/Finishes -All Facilities	77,920		$1,581,800	$0	$2,424,000	$0	$4,005,800
Equipment Systems 1 - 64	67,370		$1,458,600	$0	$259,000	$21,769,900	$23,487,500
Piping	31,840		$741,000	$0	$741,000	$0	$1,482,000
Electrical	62,970		$1,276,500	$0	$1,914,700	$0	$3,191,200
Instrumentation	113,350		$2,297,600	$0	$1,531,700	$0	$3,829,300
Paint / Insulation	40,740		$833,200	$0	$208,300	$0	$1,041,500
Silo 3 Cementation Facility	19,850		$414,800		$510,100	$1,107,700	$2,032,600
DIRECT FIELD COSTS TOTAL	610,090	$21.00	$12,595,600	$0	$10,892,800	$22,877,600	$46,366,000
SUPERVISION - CONTRACTOR	103,720		$2,141,300				$2,141,300
SMALL TOOLS & CONSUMABLES					$755,700		$755,700
MISC. EQUIP. RENTAL						$2,135,300	$2,135,300
TEMPORARY FACILITIES	18,300		$377,900		$377,900		$755,800
TEMPORARY UTILITY HOOK-UP	11,900		$245,600		$132,250		$377,850
JOB CLEAN-UP	27,450		$566,800		$188,930		$755,730
SAFETY	11,900		$245,600		$132,250		$377,850
HEALTH PHYSICS S/C	5,910		$145,200		$6,232,700		$6,377,900
CERCLA - 40 HRs/FTE			$12,600				$12,600
SITE ACCESS/JOB SPECIFIC TRAINING - 15 HRs/FTE			$4,800				$4,800
PAYROLL BURDENS & BENEFITS	-	-	$9,311,200				$9,311,200
OVERHEAD & PROFIT	-	-		$13,874,400			$13,874,400
BOND	-	-		$832,500			$832,500
SALES TAX	-	-			$1,122,800	$1,500,800	$2,623,600
INDIRECT FIELD COSTS TOTAL	180,180		$13,851,000	$14,706,900	$8,942,530	$3,636,100	$40,336,530
DIRECT & INDIRECT FIELD COSTS TOTAL	790,300	$32.45	$26,646,600	$14,706,900	$19,835,330	$26,513,700	$86,702,530
WASTE DISPOSITION - FD FERNALD			$0	$0	$0	$0	$0
RSO - FD FERNALD			$0	$0	$0	$0	$0
WASTE MANAGEMENT COSTS TOTAL			$0	$0	$0	$0	$0
PROJECT MANAGEMENT - FD FERNALD			$0	$0	$0	$0	$0
CONSTRUCTION MANAGEMENT - FD FERNALD			$17,282,500	$0	$0	$0	$17,282,500
FD FERNALD FIELD SUPPORT COSTS TOTAL			$17,282,500	$0	$0	$0	$17,282,500
ENGINEERING/DESIGN/INSPECTION - FD FERNALD Title I,II,III			$33,835,000		$0		$33,835,000
				$0			$0
ENGINEERING COSTS TOTAL			$33,835,000	$0	$0	$0	$33,835,000
SALES TAX - FD FERNALD					$0		$0
SUB-TOTAL (BASE ESTIMATE)							$137,820,000
RISK BUDGET							$0
TARGET ESTIMATE (FY 97 DOLLARS)							$137,820,000
CONTINGENCY							$0

ESTIMATE PERFORMED BY ESTIMATING SERVICES

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