COLLEGE OF ENGINEERING INDUSTRY PROGRAM

LIBRARY AGREEMENT

Materials issued under the College of Engineering Industry Program are distributed to subscribers only. However, with restrictions to protect the authors and subscribers, certain Industry Program materials are available for students to read in the Engineering Library. Any copying must involve only short passages or specific data to be used in connection with classwork, and with no intention of publication. Also, information must be kept confidential when there appears any possibility of prejudicing the proprietary rights of authors or sponsoring agencies.

College of Engineering Industry Program issue entitled:
Procedure for the design, fabrication and inspection of pressure vessels.

by H.C. Ohlgren, J.G. Lewis, & Mary Wesch, has been used in the Library by the following persons, whose signatures attest their acceptance of the above restrictions:

Name and Address	Date

COLLEGE OF ENGINEERING
UNIVERSITY OF MICHIGAN
ANN ARBOR

PROCEDURE FOR THE DESIGN, FABRICATION AND INSPECTION OF PRESSURE VESSELS

by
H. A. Ohlgren
J. G. Lewis
Marx Weech

November 1, 1954

ACKNOWLEDGMENT

The preparation of the material contained in this manual for the design, fabrication and inspection of pressure vessels has been made possible through a collection and assembly of information from many sources, reviews of fabrication technology of many industrial organizations, fabrication, inspection and installation technology employed by many construction contractors, as well as certain basic developments and advances in knowledge gained at the University of Michigan. We feel, therefore, that a wide cross-section of American industry involved in the manufacture of tanks, vessels, and other material containers for a range of construction materials heretofore unpublished have contributed much to the contents.

This manual has been prepared for the engineer engaged in industry, as well as the research worker, to serve as a guide and an aid in preparation of specifications, drawings, bills of material, purchase requisitions, as well as for the attention necessary during phases of purchasing of materials, fabrication, shipping, inspection, installation, and operation of such equipment. It is hoped that the contents are written in such a way so they can be used as a ready reference manual by persons involved in the building of pilot plants, bench scale equipment, plant replacements, as well as construction activities in new plants. This manual, coupled with the welding manual, can serve as a guide in many phases of American industry.

It is not possible to list completely all contributors of information. In particular, we wish to express our appreciation to Mr. Glenn Lecklider, Pressure Vessel Engineer, Chemical Plants Division, Blaw-Knox Company; Dr. Orlan Boston, Chairman of the Department of Production Engineering, University of Michigan; Dr. Richard Flinn, Professor of Metallurgical Engineering; Dr. Lloyd Brownell, Department of Chemical Engineering for their suggestions, comments, and contributions. We also wish to acknowledge the efforts of Miss Joan Kinne and Miss Jean Bennett, secretaries in the Engineering Research Institute, for the contributions made in organization, editing, assembly, and issuance of the material prepared.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

B1. REQUIREMENTS RELATIVE TO ALL VESSELS

1.0 GENERAL

Within this guide to specifications, the firm contracted to perform the fabrication will be referred to as the Fabricator. "Owner" refers to the firm agreeing to assume ownership of the fabricated article (s) upon satisfactory completion of the contract for fabrication.

The Fabricator shall furnish all labor, equipment and materials required to fabricate and test vessels as specified, except as amended in the contract and/or drawings. In case of conflict, not specifically noted in the contract, the Owner is to be consulted and shall make the final ruling.

Insofar as possible, all vessels shall be constructed in accordance with the applicable requirements of the A. S. M. E. Code and shall meet with the Owner's approval. "A. S. M. E. Code" refers to Section VIII in the latest edition of the A. S. M. E. Boiler and Pressure Vessel Code. Vessels shall not be stamped with the code symbol unless specifically so stated.

All materials shall conform to the nominal composition given in this guide to specifications or as indicated on the drawing or specification sheet. No substitution of material shall be permitted without written consent of the Owner.

Affidavits on the physical and chemical properties of all materials used in vessels shall be obtained from the mill or warehouse by the Fabricator and shall be made available to the Owner.

All equipment shall be fabricated of annealed stock unless otherwise specified.

Upon receipt of the Owner's purchase order and approved fabrication drawings, the Fabricator shall prepare detailed shop drawings. These shall contain all information necessary for the construction of the vessel.

Five (5) prints of all shop drawings shall be submitted for approval to the Contracting Officer. Fabrication shall not start until these drawings have been approved.

B1.1 PREPARATION OF MATERIAL

1.11 Bevelling of Plates and Heads

Plates and heads shall be accurately squared and beveled in accordance with the drawing so that the edges meet squarely and full penetration of weld can be assured.

1.12 Preparation of Openings

Openings for nozzles, manholes, etc., shall be prepared by casting, forging, punching, drilling and grinding, roughing out with an arc or acetylene cutting torch or any other approved method, and finished to size by grinding sufficiently to remove any heat-affected and/or contaminated metal. Openings shall be made accurately to the required size and shape so as to avoid excessive fill-in by welding.

1.13 Cleaning of Material

All surfaces to be welded shall be free of scale, oxides and dirt. Special care shall be exercised to insure that grease, oil, or any other undesirable film is removed from the edges to be welded.

1.14 Rolling of Plate

Plates shall be rolled to the proper curvature for their entire width. Where necessary to secure the proper curvature, the edges of the plate shall be set prior to rolling.

Head thickness shown shall be minimum and shall not be less, at any point, after fabrication.

B1.2 WELDING

Welder's qualification tests, procedures, etc., are covered in chapter C of this Guide. Requirements for welders must be met prior to any fabrication.

The degree of bevel, type of joint and amount of reinforcement shall be in strict accordance with the drawings. There shall be no valleys at the edge or center of the joint, and the weld shall be built up so that the weld metal will present a gradual increase in the thickness from the surface of the plate to the center of the weld. The deposited metal shall be fused with the parent metal at all sections of the weld. Welds, unless otherwise specified, shall be reinforced 25% (1/16" minimum) for joints welded from one side only and at least 15% (1/32" minimum) for joints welded from both sides. Welds shall not be finished by grinding unless called for on the drawing. Slag shall be removed by tapping with a blunt hammer followed by wirebrushing or pickling.

The welding rods shall be selected to insure that the deposited metal will conform to the minimum specifications for that of the parent metal. Rods which contain excessive boron or which are coated with shellac shall not be used.

B1.3 ALIGNMENT AND TOLERANCES

1.31 Alignment of Sheet Stock

At no point shall the sheet on one side of the joint be offset with respect to the sheet on the other side in the excess of the following:

a. Longitudinal seams
10% of the minimum thickness of the plate or sheet

b. Girth and headseams
25% of the minimum thickness of plates
10% of the minimum thickness of clad material
10% of the minimum thickness on single "V" welds

Unless otherwise noted on the drawing, vessels shall be circular within the limits prescribed by Paragraph UG-80 of the latest edition of the A. S. M. E. Code.

1.32 Nozzles

All nozzle flanges shall be squared within 1/32" for pipe sizes up to and including 2" and within 1/16" for sizes greater than 2". The deviation from "square" is to be measured across the flange O.D. After welding, flanges shall be re-squared and faces re-machined if necessary to insure proper bolt and gasket bearing.

Flange faces on tubular heat exchangers are to be machined so the faces meet squarely and the flange shall be squared with the shell.

Unless otherwise noted on the drawing, location of openings shall not vary more than plus or minus 1/16".

1.33 General Overall Dimensions

Tolerances on overall dimensions shall be as noted on the drawings. Unless otherwise noted, all thickness specified are nominal and usual mill tolerances are permissible.

When specified as "minimum", the thickness after fabrication shall not be less than noted at any point.

The Fabricator may use for any part material which is of thickness greater than specified if such increased thickness will result in greater ease of fabrication or in a lower cost.

Tray plates and columns shall be levelled to within 1/8" unless otherwise specified. In tray-column-shells, the two lap-joint-flange-faces of the column section shall be parallel.

B1.4 TESTS

1.41 Radiographing

Where radiographing or spot radiographing is specified, it shall be carried out in accordance with the requirements of Paragraphs UW-51 and UW-52 of the A. S. M. E. Code.

1.42 Chemical and Corrosion Tests

Unless otherwise specified in the contract specifications or drawings, chemical and corrosion tests shall be conducted in accordance with test requirements set forth in this Guide to specifications under sections devoted to specific metals and shall be in addition to the test requirements specified in Chapter C, relative to welding.

The Fabricator shall submit the specified number and type of test specimens to a certified testing laboratory approved by the Owner. The chemical analysis of the specimen plate material should be forwarded by letter to the testing laboratory.

The stub end of the electrode or filler wire used in making the welded specimen shall be forwarded with the specimen and analyzed for chemical composition.

All tests specimens shall be tagged to give complete identification, including the following information:

a. Name of Fabricator.

b. Name of welding operator.

c. Symbol or number of operator.

d. Vessel drawing number.

e. Type of material.

f. Type and size of welding rod or wire.

g. Type of welding process.

h. Type of joint and number of passes.

i. Treatment after welding, if any.

The Fabricator shall forward six (6) copies of the laboratory report to the Owner.

1.43 Hydrostatic, Hammer and Air Tests

The test and test pressures shall be in accordance with those indicated on the drawing. A general sweating of a weld under pressure shall cause rejection of the joint involved.

The hammer test shall consist of striking the plate at 6 inch intervals on both sides and over the full length of all welded seams. The weight of the hammer in pounds shall be equal to the thickness of the shell in tenths of an inch and the blows shall be struck with a force equivalent to an 8 foot free fall of the hammer head. The edges of the hammer shall be rounded to prevent defacing the plates. In no case shall the temperature of the vessel or the liquid be less than 50°F. during the test and the test pressure shall not be applied until the vessel and liquid reach this minimum temperature.

Air tests, when required, shall be carried out in conformance with Paragraph UG-100 of the A. S. M. E. Code. The vessel or portion of the vessel to be air tested shall be submerged so that all welded joints are completely under water. The air test pressure shall be applied and maintained for a sufficient length of time to permit inspection of all welded and mechanical joints.

For acceptance under the air tests, no leaks shall be present either in welded joints or in mechanical joints specified to be tight.

Where mechanical joints are broken following the specified tests, new gaskets shall be furnished with the vessel. For such joints, gaskets of the same material and design as employed in the tests shall be supplied.

B1.5 DEFECTIVE MATERIAL AND WORKMANSHIP-GUARANTEE

Defective material shall not be used.

No peening or caulking shall be permitted in repairing leaks caused by cracks, pinholes, or blowholes. Such leaks shall be repaired by grinding or chipping out the weld to the bottom of the joint and then rewelding.

Proper preheating of the metal shall be required in the vicinity of welding repairs being made to seal any hole or crack in a previously welded joint. The purpose of such preheating is to relieve any added stress on the weld section.

The Fabricator shall guarantee all material and workmanship to be free of defects for a period of one (1) year from the time of shipment and shall repair or replace at his own expense any vessel proven defective during this interval.

B1.6 EQUIPMENT IDENTIFICATION AND MARKING

1.61 The shell plates shall be rolled with the heat numbers on the outside surface of the vessel and the heat numbers on the heads shall be in evidence so that a proper check may be made against the mill test reports of plate and head material.

1.62 Each vessel shall be furnished with a metallic nameplate containing the following information:

Name of Fabricator

Design Pressure

Design Temperature

Test Pressure

Date

Owner's Number for Vessel

Fabricator's Number for Vessel

The plate shall be of the same material as the vessel to which it is attached and the legend shall be affixed by metal-stamping. The plate shall be welded to the vessel so as to be easily read when the vessel is in the installed position.

B1.7 FACTORY INSPECTION

All vessels shall be subject to factory inspection by a representative of the Owner. The Fabricator shall notify the Owner at least three (3) days in advance of the date on which equipment will be ready for testing.

B1.8 PREPARATION FOR SHIPMENT

Painting, if required, shall be as noted on the drawing and/or specification sheet. Vessels should be cleaned of rust, slag, grease, dirt, etc. and thoroughly dried before painting.

Temporary bracing within a vessel is not to be used without the written consent of the Contracting Officer.

Vessel openings are to be blanked off using blind wooden flanges on flanged openings, wooden plugs in welding stubs, and suitable thread protectors on screwed connections.

The Owner will advise the Fabricator as to how shipment is to be made.

B2. STAINLESS STEEL VESSELS

2.0 CHEMICAL AND MECHANICAL REQUIREMENTS

Unless otherwise specified, stainless steels shall conform to the following requirements:

Type 304 Grade "S" Modified

Chemical Composition, %

Carbon	max.	0.08
Manganese	max.	2.50
Phosphorous	max.	0.035
Sulfur	max.	0.03
Silicon	max.	0.85
Chromium	min.	18.0
Nickel	min.	8.0

Mechanical Properties (Annealed)

Tensile Strength	75,000 psi, min.
Yield Strength, 0.2% offset	30,000 psi, min.
% Elongation in 2 inch	30 min.

- Type 304 ELC -

Chemical Composition, %

Carbon	max.	0.030
Manganese	max.	2.50
Phosphorous	max.	0.035
Sulfur	max.	0.03
Silicon	max.	0.85
Chromium	min.	18.0
Nickel	min.	8.0

Mechanical Properties (Annealed)

Tensile Strength	75,000 psi, min.
Yield Strength, 0.2% offset	30,000 psi, min.
% Elongation in 2 inch	30 min.

- Type 309 ELC -

Chemical Composition, %

Carbon	max.	0.030
Manganese	max.	2.50
Phosphorous	max.	0.035
Sulfur	max.	0.03
Silicon	max.	0.85
Chromium	min.	22.0
Nickel	min.	12.0

Mechanical Properties (Annealed)

Tensile Strength	75,000 psi, min.
Yield Strength, 0.2% offset	30,000 psi, min.
% Elongation in 2 inch	30 min.

Type 316 Grade "M" Modified

Chemical Composition, %

Carbon	max.	0.08
Manganese	max.	2.50
Phosphorous	max.	0.035
Sulfur	max.	0.03
Silicon	max.	0.85
Chromium	min.	17.0
Nickel	min.	10.0
Molybdenum	min.	2.0

Mechanical Properties (Annealed)

Tensile Strength	75,000 psi, min.
Yield Strength, 0.2% offset	30,000 psi, min.
% Elongation in 2 inch	30 min.

Type 347 Grade "C" Modified

Chemical Composition, %

Carbon	max.	0.08
Manganese	max.	2.50
Phosphorous	max.	0.035
Sulfur	max.	0.03
Silicon	max.	0.85
Chromium	min.	17.0
Nickel	min.	9.5

Columbium (Niobium), 10 x C min., 1% max.

Mechanical Properties (Annealed)

Tensile Strength	75,000 psi, min.
Yield Strength, 0.2% offset	30,000 psi, min.
% Elongation in 2 inch	30 min.

- Carpenter 20 -

Chemical Composition, %

Carbon	max.	0.07
Manganese	max.	0.75
Silicon	max.	1.00
Chromium	min.	20.00
Nickel	min.	29.00
Molybdenum	min.	2.00
Copper	min.	3.00

Columbium (Niobium), 10 x C min., 1% max.

Mechanical Properties (Annealed)

Tensile Strength	85,000 psi, min.
Yield Strength 0.2 offset	35,000 psi, min.
% Elongation in 2 inch	50 min.

B2.1 PREPARATION OF MATERIAL

In order to minimize carbide precipitation during electric arc cutting, the air arc method shall be used. All foreign material resulting from this operation shall be removed from the metal.

Severe grinding shall be avoided. The temperature may rise above 850°F. from grinding too long in one place and cause carbide precipitation. Severe grinding will also cause the weld to sag as though it were ground too deep and give an appearance similar to an undercut.

B2.2 WELDING

In welding vessels which are not to be fully annealed, the parent metal should not be allowed to remain in the 850-1600°F. range longer than 7 min. for Carpenter 20 and Type 347, 3 min. for Type 316, 309 and 304.

An air or water quench should be applied immediately following the welding of light gauge material and a water quench should be applied to heavy gauge material. Sufficient heat should be left in the metal to vaporize all the water.

The jet used for cooling should be directed away from the electrode and should not interfere with the inert gas shield.

Cooling air should be filtered and free of carbonaceous material.

Preheat temperature should not exceed 600° F.

B2.3 HEAT TREATMENT

2.31 All forms of stainless steel used in fabrication shall be supplied in the annealed condition which results from rapid and uniform cooling (40 seconds max.) by quenching in water or air from the following temperature ranges.

Types 304 and 347	1900°F. - 2000°F.
Types 309 and 316	2000°F. - 2100°F.
Carpenter 20	2050°F.

2.32 Pressed or spun heads or sections which have been severely cold worked and which are to be used on vessels which will not be heat treated after fabrication shall be annealed after forming using the method noted in Paragraph 2.31.

2.33 Equipment fabricated of Type 304 or Type 316 steel and intended for corrosive service must be heat treated after welding by quenching in air or water to obtain maximum corrosion resistance. The metal shall be held at a temperature between 1850°F. and 2000°F. for one hour per inch of thickness, but in no case less than a half hour.

2.34 In the event that plate thickness or shape of vessel makes annealing after fabrication impractical, weldments shall be quenched in accordance with Paragraph 2.2.

2.35 Heat treatment shall be performed in an atmosphere free of any gas containing carbon.

2.36 Vessels shall be braced, if necessary, to prevent distortion.

2.37 When heat treatment is specified, it shall be taken as full anneal.

B2.4 TESTS

2.41 Chemical Analysis

Specimens of the stainless steel weld metal shall be submitted for chemical analysis to a certified testing laboratory, in accordance with Paragraph 1.42. One (1) test plate measuring 4 inches x 4 inches minimum with a weld down the center (for material less than 3/16 inch thick, eight lineal inches of weld will be required) shall be required for each vessel and shall be a detailed representation of the longitudinal or girth seam of the vessel and produced by the welder who welded the vessel seam.

The chemical analysis of the weld metal shall be within the range specified for the parent metal.

2.42 Corrosion Tests

Corrosion tests may be required as specified in the contract specifications or drawings and when required shall be made by a certified laboratory in accordance with Paragraph 1.42. Tests shall be made on samples containing at least 1 inch of the weld and a minimum of 1 inch of the base metal to either side of the weld.

The following are types of tests which may be specified:

Boiling Acidified Copper Sulfate Test (Strauss Test)

Weld specimens shall be boiled for 72 consecutive hours in a solution of the following composition:

47 cc sulfuric acid (sp. gr. 1.84)

13 grams copper sulfate (Cu SO - 5 H_2O)

Per one liter of solution

The specimen shall be boiled in a suitable flask, using a reflux condenser to prevent variations in the concentration. After this treatment, the specimen shall not have lost its metallic ring and shall bend through an angle of at least 150° without evidence of cracks or disintegration.

Nitric - Hydrofluoric Acid Test

Weld specimens shall be tested in a solution containing 3 per cent hydrofluoric acid and 10 per cent nitric acid heated to a temperature of 170°F. for a period of one hour. After this treatment, the specimen shall show freedom from corrosion attack and shall be capable of withstanding a bend through an angle of 180° without evidence of cracks or disintegration.

Boiling 65 per cent Nitric Acid Test

Parent metal and weld specimens shall be subjected to five 48-hour boiling periods in 65 per cent nitric acid, renewing the acid after each period.

The mean corrosion rate for five 48-hour boiling periods shall not exceed .0015 inches penetration per month.

B2.5 PICKLING AND CLEANING

2.51 All stainless steel equipment shall be furnished free of scale and contamination by foreign material.

2.52 The following pickling solution may be used for removing scale from the stabilized steels or austenitic steels that have been fully annealed.

Concentration by volume: 20% nitric acid (Sp. Gr. 1.42)
3% hydrofluoric acid

Solution temperature should be between 120° and 140°F.

The duration of immersion will vary depending on the oxide present. The solution should not be allowed to become exhausted as this would cause pitting. Pickling should be followed by a thorough washing with clean, warm water.

2.53 The following pickling solution may be used for removing scale from nonstabilized austenitic steel that has not been fully annealed.

Concentrations by weight: 8-12% sulfuric acid (Sp. Gr. 1.84)
2% rock salt

Solution temperature should be warm but not to exceed 160°F. Duration of immersion should run from 10 to 20 minutes and should be followed by a thorough wash with clear warm water.

2.54 Unless otherwise noted, all surfaces shall receive a final cleaning by immersing 30 to 60 minutes in a 20% nitric acid (by volume) solution at 130° - 140°F. This should be followed by a thorough wash with clean, warm water.

NOTE: Articles pickled in the nitric-hydrofluoric acid solution do not require the final dilute nitric acid wash.

2.55 If immersion is impractical due to the size or shape of equipment, the surfaces may be swabbed with the acid solution. This procedure requires careful washing of the section to which acid has been applied.

2.56 After the final cleansing operation, stainless steel equipment should be handled with great care to avoid contamination by foreign material.

B3. NICKEL, MONEL AND INCONEL VESSELS

B3.0 CHEMICAL AND MECHANICAL REQUIREMENTS

Unless otherwise specified, chemical and physical requirements of these alloys shall conform to A. S. T. M. standards as follows:

- Nickel -

Plate-Sheet-Strip	B162-49T
Pipe and Tubing	B161-49T
Rod and Bar	B160-49T
Heat Exchanger Tubes	B163-49T

Unless otherwise specified, "Nickel" shall be commercially pure nickel.

Sheet used for spinning shall be low-carbon "spinning quality" sheet. "Deep-drawing quality" sheet and strip shall be used for parts requiring deep-drawing.

Plate intended for tube sheets shall be "as rolled" with a descaled surface and "press-flattened."

- Monel -

Plate-Sheet-Strip B127-49T

Pipe and Tubing B165-49T

Rod and Bar B164-49T

Heat Exchanger Tubes B163-49T

Grain size of "deep-drawing quality" and "spinning quality" sheet and strip shall be in accordance with B 127-49T, Section II.

Plate intended for tube sheets shall be "as rolled", "descaled" and "press-flattened."

- Inconel -

Grain size of "deep-drawing quality" and "spinning quality" sheet and strip shall be in accordance with B 168-49T, Section II.

Plate intended for tube sheets shall be "as rolled", descaled, and "press-flattened."

B3.1 PREPARATION OF MATERIAL

Lubricants containing sulfur or low melting point metals shall not be used for forming operations if the work is to be subsequently annealed or welded.

Lubricants, crayon marks, etc., should be completely removed prior to annealing.

All foreign material shall be removed from the area that is to be welded or heated by welding. The area should extend at least 2 inches beyond the weld. Surface film formed by cleaning or degreasing operations must be removed. This may be accomplished by cleaning with carbon tetrachloride and wiping with a clean cloth, or by washing with hot trisodium-phosphate.

B3.2 WELDING

3.21 Joint Design

Bevelling will not be required for material 0.109 inches or thinner. Erratic penetration will result if material thicker than 0.109 inch is welded from one side only without bevelling.

"V" joints shall be used up to and including 3/8" thickness and "U" joints for materials heavier than 3/8".

Proper accessibility shall be provided by bevelling "V" joints to at least an 80° included angle and "U" joints beveled to a 15° side angle and a 3/16" to 5/16" bottom radius.

Joints shall be welded from both sides. Where this is not possible, the joint spacing shall be increased as shown in Chapter C.

The use of back-up rings shall be avoided in cases where the ring cannot be removed after welding.

Back-up or chill bars shall contain a groove of the proper contour to permit full penetration. Ungrooved bars shall not be used.

High heat input and excessive penetration shall be avoided.

3.22 Gases

Argon shall be used for 16 BWG and lighter.

Helium shall be used for over 16 BWG.

Gases shall be of the "high purity welding grade."

3.23 Welding Procedures

Excessive agitation of the weld puddle and excessive air movement which might disrupt the protective atmosphere around the arc and weld joint shall be avoided.

The arc length shall be maintained as short as practical.

The weld root shall be protected against oxidation and root cracking by providing an inert gas backing.

Flux backings shall not be permitted unless specifically so stated on the specification sheet and/or drawing.

B3.3 **HEAT TREATMENT**

Heat treatment shall be required as specified on the drawing and/or contract specifications.

3.31 Soft annealing shall be applied to material which has been hardened by cold working for the purpose of softening the cold worked structure and relieving macro and micro internal stresses.

3.32 Stress relieving shall imply a moderate (1000-1300°F.) thermal treatment designed to reduce or relieve the internal macro-stresses which exist in the metal as a result of cold working, machining, casting or welding operations.

3.33 Stress equalizing shall imply a low temperature (500-1100°F.) thermal treatment designed to improve strength and ductility of cold and hot worked material.

3.34 A sulfur-free reducing atmosphere shall be provided during heating and cooling.

A reducing atmosphere shall be defined as one with a minimum of 2% carbon monoxide plus hydrogen (preferably 4%) with uncombined oxygen not exceeding 0.05%.

Furnace atmosphere shall be closely controlled to prevent fluctuation between reducing and oxidizing conditions. (This precaution is required to prevent intercrystalline attack with the resulting embrittlement.)

Dirt, lubricants, paint marks and all other adherent substances that may contain sulfur or other harmful ingredients shall be removed before heating.

Work shall be supported entirely clear of the furnace bottoms and protected from roof spallings.

Time and temp. shall be closely controlled during heat treatment to prevent excessive grain growth.

B3.4 TESTS

3.41 Detection of Embedded Iron

All surfaces that will be exposed to corrosive media shall be tested for the presence of embedded iron. This test shall be performed after fabrication is complete except that small or intricately shaped vessels and/or parts thereof may be tested prior to final assembly.

For relatively small equipment, the ferroxyl test shall be used. It shall be carried out by applying to the surface, a potassium ferricyanide solution made up in approximately the following proportions:

10 gm.	Agar Agar
1 gm.	Sodium Chloride (chemically pure)
1 gm.	Potassium Ferricyanide
1 liter of H_2O	

Solution shall be boiled until all the agar-agar is dissolved and a clear liquor is formed. The warm solution should be applied to the surface and allowed to remain for at least one (1) hour and possibly longer. The solution will jell on cooling and the presence of iron on the metal surface will be indicated by the development of blue spots in the jell. Tiny specks of iron that may have collected on the surface in the form of shop dust will show up as minute blue spots. A distinction should be made between these and the larger spots that develop in the case of embedded iron. In the former instance, harmful effects would not result from loose dust and therefore no provision need be made for its removal since it will be removed along with the jell. Spots of larger proportion present on the surface shall be removed by applying a paste pickle. The detection test shall be repeated to ascertain that all traces of embedded iron have been removed.

For testing large equipment, a solution of 1% sodium chloride may be used. The salt shall be of the chemically pure grade. In the dilute salt solution, iron rust will form around the iron particles in 12-14 hours. The equipment may be immersed in the salt solution or sprayed with the aid of an atomizer.

3.42 Corrosion Tests

Corrosion tests shall be required as specified in the contract specifications or drawings. Tests shall be made on samples containing at least 1 inch of the weld and a minimum of 1 inch of the base metal to either side of the weld. The sample shall be a detailed representation of a longitudinal or girth seam of the vessel and produced by the welding operator who welded the vessel seam.

Tests shall be performed by a certified testing laboratory in accordance with Paragraph 1.42.

B3.5 PICKLING AND CLEANING

All surfaces subjected to heat treatment and/or welding operations shall be thoroughly cleaned of all foreign matter prior to the performance of these operations. Cleaning operation must be thorough.

Soluble oils, tallow, fats and fatty acid combinations shall be removed using hot (180°F. - 200°F.) 10-20% solution, of equal parts, of sodium carbonate and trisodiumphosphate.

Sodium hydroxide may be used in place of sodium carbonate.

Film left from cleansing operations utilizing carbon tetrachloride, gasoline, kerosene and other similar solvents shall be removed by a final dip in hot trisodiumphosphate, a 10-20 per cent solution of either sodium carbonate or trisodiumphosphate, or a mixture of both followed by thorough rinsing with water.

The white surface produced by annealing in a strongly reducing, sulfur free atmosphere may be removed by "flash pickling." Care must be exercised to prevent overpickling and/or etching.

Paste pickle may be used when the size or shape of the vessel makes total immersion or spraying impractical.

All equipment shall be furnished clean and free of oxide film and/or scale.

B4. ALUMINUM AND ALUMINUM ALLOY VESSESLS

B4.0 CHEMICAL AND PHYSICAL REQUIREMENTS

Unless otherwise specified, chemical and physical requirements of these materials shall conform to A. S. T. M. standards as follows:

Sheet and Plate	B178-52 T
Pipe and Tubing	B274-52 T
Bars, Rods and Shapes	B273-52 T
Heat Exchanger Tubes	B234-50 T

Unless otherwise specified, heat exchanger tubes shall be furnished in the intermediate temper.

B4.1 PREPARATION OF MATERIAL

All foreign material shall be removed from the area that is to be welded. The area should extend at least one inch beyond the weld. Dirt and grease may be removed with carbon tetrachloride or a similar solvent. An alkaline cleaning solution may also be used. (See Para. 4.5). Surface film left from cleaning or degreasing operations should be removed by wiping with a clean cloth. Surface oxide shall be removed from areas to be welded. This may be accomplished by wire brushing, rubbing with steel wool and/or chemical cleaning (See Para. 4.5).

B4.2 WELDING

4.21 Aluminum and aluminum alloy vessels shall be welded with the argon-shielded tungsten-arc, using alternating current and high purity argon.

4.22 Welding procedures, welders and welding operators shall be qualified in accordance with Section IX of the A. S. M. E. Code. The minimum tensile requirements for reduced-section specimens shall be in accordance with A. S. T. M. requirements for the base metal. Specimens of heat-treatable alloys shall be post-weld heat treated in accordance with the thermal treatment specified for the completed vessel.

4.23 The single-vee butt joint shall be used on stock up to 1/2 inch in thickness. A double-vee butt joint shall be used on stock thicker than 1/2 inch where the design of the assembly being welded permits access to the back of the joint for a second pass. The angle of the included "vee" should be 60 degrees and the nose of the "vee" should have a 1/8 to 1/4 inch land depending on the thickness of pieces being welded. An inert-gas backing shall be used on all joints being welded where practical.

4.24 To minimize weld porosity, the following points are recommended:

a. Clean joint surfaces and welding rod or wire so as to remove all traces of grease or any other substance that could evolve gas.

b. Likewise, eliminate moisture. Welding rod or wire which has been exposed to moist air is particularly detrimental.

c. Preheat to approximately 400° F.

d. Agitate weld puddle to promote escape of gas.

e. Avoid vertical and overhead welding as much as possible.

f. Do not exceed recommended arc velocity.

4.25 Filler alloys containing greater than 5.5% magnesium shall not be used.

B4.3 HEAT TREATMENT

Unless otherwise specified, vessels fabricated of heat-treatable alloys shall be thermally treated to secure the temper as specified for the material on the drawing or specification sheet. The temperature limits required for thermal treatment shall be held within 10°F. of the temperature recommended by the mill. Furnaces, if used, shall be free of combustion gas.

Thermal stress-relief will not be required or permitted.

B4.4 TESTS

4.41 Freon Leak Test

Vessels which are to be gas-tight shall be subjected to the Freon leak test when specified on the drawing or contract specification sheet. Unless otherwise specified, the vessel shall be charged with Freon gas at atmospheric pressure and then pressurized with air to the extent of 1-1/2 times the vessel design pressure. While under pressure, all welds and mechanical joints shall be examined for leaks for their full length, using either a flame type or electronic type leak detector.

When specified, vessels requiring sensitive leak detection shall be tested using the electronic leak detector.

4.42 Corrosion Tests

Corrosion tests shall be required as specified in the contract specifications or drawings. Tests shall be made on samples containing at least 1 inch of the weld and a minimum of 1 inch of the base metal to either side of the weld. The sample shall be a detailed representation of a longitudinal or girth seam of the vessel and produced by the welding operator who welded the vessel seam.

4.43 Reporting Corrosion Tests

Tests shall be reported in accordance with requirements set forth in Paragraph B1.42.

B4.5 PICKLING AND CLEANING

Where required surface oxide may be removed by pickling in a 5 per cent solution of sodium hydroxide at 160° F. for 30 seconds to 1 minute, followed by a water rinse, a sulfuric acid dip and, finally, a thorough water rinse. Caution: These solutions, as well as other cleaning solutions, may produce severe etching and it is advisable to test the procedure on scrap material before proceeding with the cleaning operation.

Nitric acid shall not be used for cleaning joints that are to be welded.

Alkaline cleaning solutions may be used for removing light grease and oil films, dirt and other foreign material. These solutions should contain an inhibitor and be used hot (160 to 180° F.) for 3 to 5 minutes. Some suggested cleaners are (a) tetrasodium pyro-phosphate with an inhibitor such as sodium metasilicate and (b) sodium carbonate or trisodium phosphate inhibited with sodium disilicate.

If the size or shape of the vessel makes immersion impractical, the above solutions may be applied by swabbing.

B5. RUBBER-LINED STEEL VESSELS

5.0 CHEMICAL AND MECHANICAL REQUIREMENTS

All vessels to be rubber-lined shall be fabricated from steel conforming to the requirements of A. S. T. M. designation A285-49T, grade C, flange quality steel, unless otherwise specified on the drawing or specification sheet. The rubber lining shall conform to the details of composition and fabrication as noted on the drawing or specification sheet and shall be bonded to the vessel surface.

5.1 PREPARATION OF MATERIAL

5.11 The vessels shall be fabricated with a minimum number of pieces and all sharp edges of sheared plates shall be removed on the inside of the vessels. All corners that are to be covered by the lining shall be formed or ground to a minimum radius of 1/8".

5.12 Alignment and tolerances as specified in paragraph B1.3 are to apply, but in no case shall mis-alignment of plates and butt weld seams exceed 1/8".

5.13 The vessel surfaces shall be sand-blasted until a bright surface is exposed. All rust, grease, weld spatter and scales shall be removed to the virgin metal.

5.14 Unless otherwise noted on the drawing or individual specification sheet, all flange openings to be lined shall be flat-faced with the lining covering the full face. Holes shall be punched to receive the flange bolts. If the lining material is too hard to serve satisfactorily as a flange gasket, the fabricator shall furnish separate gaskets made from softer stock. If the lining material is soft and subject to crushing, the fabricator shall furnish each flange a compression ring fitted outside the bolts circle and cemented to the flange. In this case, the softer lining shall extend over the flange face to the compression ring.

5.2 WELDING

5.21 All welding shall conform to the general requirements of paragraph B1.2.

5.22 All joints over which lining is to be applied shall be continuous solid welds. All welds shall be smooth and with no porosity holes, high spots, lumps or pockets. All corners shall be ground to a minimum radius of 1/8".

5.23 Partitions, braces, supports, or other attachments on the inside of the vessel, shall be fitted flat against the adjacent surface and full-welded from all sides. Spot or intermittent welding is not permissible.

5.3 HEAT TREATMENT

Vessels shall be thermally stress-relieved when specified on the drawing or specification sheet, or when required by paragraph UCS-56 of the A. S. M. E. Code, excluding the requirements of paragraph UW-2 of the code. The service restrictions of paragraph UW-2 will be judged by the Owner. When stress relief is required, it shall be performed in accordance with the procedures of paragraph UW-40 of the A.S.M.E. Code.

5.4 TESTS

5.41 <u>Hydrostatic and Air Tests</u>

When the Hydrostatic or Air Tests are required, they shall be performed before the vessel has been lined.

5.42 Spark Test

Vessel linings shall be spark tested when so specified on the drawing or specification sheet.

5.43 Corrosion Test

Where corrosion tests are required by the drawing or specification sheet, the fabricator shall prepare a test specimen of the lining material measuring approximately 4" x 6" with a longitudinal lap joint. The test specimen shall be formed by the same process as used for lining the vessel. The test shall be made by a certified testing laboratory in accordance with paragraph B1.42.

5.5 CLEANING

After a vessel has been lined, the interior shall be thoroughly cleaned of all foreign material such as cement drippings, dirt, grease, etc., and thereafter kept closed to prevent re-entry of dirt.

PROCEDURE FOR PRESSURE VESSELS (API-ASME.)

The following procedure attempts to cover all conditions obtained in a pressure vessel. Select only those conditions that apply to your particular vessel. For unforseen conditions and special requirements use engineering judgement as to formula and location in the calculation.

Write down all applicable headings and subheadings as given herein and in the order given below. Set down all calculations and subtotals-these are your work sheets. Set down each result called for in formula in the manner given and underscored. Omit word "Result".

I <u>Shell.</u>
Large Section: [Thickness 'T'
Test Pressure T.P.]

Other Sections:---As above

II <u>Heads.</u> [Give Type - Calculations for each diameter]

A. External Heads: [Thickness 'T'
Test Pressure T.P.]

B. Internal Heads: [Thickness 'T'
Plugwelds or Riveted Joint
Test Pressure T.P.]

C. Conical Sections: [Thickness 'T'
Test Pressure T.P.]

III <u>Manholes.</u>

IV <u>Nozzles.</u>

[List series, size, dwg #, & Rating at Design Temp. & Test Pressure at Atmos. Temp for each different. M.H. & series of nozzles.]

V Test Pressure To Be Applied To Vessel--#/□"
Smallest of all test pressures from above.

(C-1) VI Allowable Working Pressure at Atmos.
Temp. (uncorroded) --#/□" = $\frac{\text{Test Pressure.}}{1.5}$

(C-1) VII Stress in Long-Joint at Test
Pressure --#/□" (Calculation For Each Diam.
& Thickness of Shell).

VIII Vessel Thickness To Withstand Test Pressure.

A. Shell (Calculation for each diam. & thickness.)

B. Heads

Note: 2:1 seamless elliptical heads same as shell of same thickness. omit heads without connections.

IX Reinforcing Plate Thickness.

A. Shell.] calculation for each **diam. and**

B. Heads.] thickness covered by VIII

X Pad & Weld Sizes

A Thru C Pad & weld sizes (Std Practice)
D Thru F Special size & head pads & welds
G Investigation of pad requirements.

XI Weights (Separate Sheet Prefered)

A. Weights new & corroded vessel

B. Weights to appear on drawing.

XII Moments.

Wind about base & other planes (as req'd)
Earthquake. (if req'd)

XIII Anchor Bolts.

No & Size

XIV Skirt

A. Thickness, stress & welds

B. Allowable stress (Sheet)

XV Base Ring

Thickness

XVI Stress in Tower Shell.

Data Sheet Use only for high stress.

XVII Deflection. (if required)

Date Sheets

XVIII Internals-

A thru to end. Pans, discs, baffels etc.
Calculate weight under each item.

NOTES. (c-1) Item VI & VII required only when vessel is Code Inspected & Stamped. For estimates follow proceedure on sheet
Dot & dash line indicates start of a new sheet. The subject matter between lines is not, necessarially, restricted to one sheet.
For Nomenclature see sheet

PROCEEDURE FOR ESTIMATES. (API - ASME)

Calculations for estimates are to be in such form that they can be used as final calculations for contracts. Space for missing items should be left and weights should always appear on a sheet exclusively for weights.

Occasionally items are required in addition to those listed below in which case refer to contract proceedure for formula and location.

I Shell.

Large Section Thickness "T" only
Other Sections " " "

II Heads. (Give type. One set cals. for each diameter etc.)

A. External
B. Internal
C. Conical

] Thickness "T" Only

III Manholes.
IV Nozzles.

[List series, size, dwg.# & rating at design temperature for each different manhole & series of nozzles.

XI Weights. (Seperate Sheet)

A. Weights new & corroded vessel
B. Weights to appear on drawing:

XII Moments.

Wind about base.
Wind about other planes as required
Earthquake (if required)

XIII Anchor Bolts

No & Size.

XIV Skirt

A. Thickness & stress

B. Allowable stress (Sheet)

XV Base Ring.

Thickness

XVI Stress in Tower Shell.

Data Sheet Use only for high stress

XVII Deplection. Only when required.

Data Sheets thru

XVIII Internals.

A thru to end. Pans, discs, baffels etc.
Calculate weight under each item.

NOTE: Space must be left in estimate calculations to permit the inclusion of required (but missing) items if the estimate becomes a contract.

NOMENCLATURE.

P = Pressure in pounds/sq.inch.

E = Efficiency of joint. For welded joint see table 1 ¶ W-319 api-asme code.

S = Stress in pounds/sq.inch. Design conditions. For 2SE see sheet

S_2 = Allowable stress at atmospheric temperature.

C = Corrosion Allowance.

t = Theoretical plate thickness.

T = Commercial plate thickness.

TP = Test Pressure

I.D. = Inside Diameter

O.D. = Outside "

D = I.D + ZC

$D_{\not{m}}$ = I.D + T (for test pressure)

D_m = I.D + C + T (for design pressure)

PRESSURE VESSEL CALCULATION PROCEEDURE.

I Shell

(a) thickness: $t = \frac{p \times D}{2SE-p} + C$ or (b) $\frac{D + 100}{1000} + C =$

Use larger value (a) or (b) but not less than 1/4" fully corroded (1/4" + C)
Select smallest commercial plate thickness containing "t" (or 1/4" + C)
Call thickness of selected plate "T".
For '2SE' factors see sheet (Result) USE ___" PLATE

(c) Test Pressure: TP. $= \frac{2SET}{D} \times 1.5$ (Result) T.P. ____#/☐

II Heads. Consult manufacturer's tables for thickness limitations before selecting "T".

A External Heads. (Bott welded joint to shell. T not less than T of shell)

Ellipsoidal. With head ratio of z = 1 no calculation is required. Use same "T" as shell. T.P. will be greater than shell if head is in one piece or equal to shell if head has same kind of joints as shell.

(a) Thickness: $t = \frac{p D_m V}{2SE} + C$ (b) T.P. $= \frac{2\ SET}{D_m V}$ (Result)USE-"PLATE
T.P.___#/☐

(c) Minimum: $t = \frac{p D_m}{4SE}$ V = a factor (= 1 for 2:1 heads)Fig 4 W311 api asme Code
E = 1 for seamless heads.

Flanged and Dished. Assume a trial value of T for determing ω. & adjust.

(a) Thickness $= t = \frac{pR_c \omega_1}{2SE} + C$ T.P. $= \frac{2\ SET}{R_\phi \omega_2}$ (Result) USE___"PLATE.
" T.P.___#/☐

R_c = Dishing Radius + C + $(\frac{T-C}{2})$ R_ϕ = Dishing Radius $+(\frac{T}{2})$

K_r = Knuckle Radius + C + $(\frac{T-C}{2})$ K_r = Knuckel Radius $+(\frac{T}{2})$

ω_1 & ω_2 are factors (Fig 5 W311 api asme code)based on the following ratios: -

For ω_1 ratio $= \frac{Kr}{R_c}$ For ω_2 ratio $= \frac{Kr}{R\phi}$

For numerical values of ω_1 & ω_2 see sheet

Calculations set up to investigate other thickness should be left standing & marked "Not Used".

B. Internal Heads. Corrosion & pressure on both sides - Use formulea for external heads, of some type, but Divide "t" by 0-6 before adding corrosion. Then add '2C: Note that $R_c = R_\phi$ & $K_r = K_c$ for F&D heads when corrosion is equal on both sides of head. (Result) USE _____" PLATE

Plug Welds. Use with shell plates up to 5/8" thickness, maximum. (Thickness of head plate has an influence) For shell "T" over 5/8" use Riveted Joint.

The full fillet weld, head to shell, required by code can carry a maximum of 80% of the load on the head (= .8L). Load on plugs not less than .2L

Total load on head: $L = p \frac{\pi}{4} D^2$ Let T_{ph} = head thickness.

Maximum capacity of fillet weld (not less than .8L) = .8SE x .707 $(T_{ph} - C) \times \pi D$

Plug weld at least 1/4" larger in diam. than thickness of plate (but not less than 1" diam) up to 2" plate thickness. For thicker plates use $2\frac{1}{4}$" diam. plugs. For internal heads use 1" diam. plug welds spaced approx. 12" circular pitch as minimum.

Allow. load per plug: L_p = .63 (min.diam. of plug - 1/4")^2 x .8S - Min. Number of plugs: $= .\frac{2L}{Lp}$ (RESULT) USE____, PLUGS_____" DIAM.

Test conditions check:

Total load on head: $L_{tp.} = T.P. \times \frac{\pi}{4} \times I.D.$

Maximum capacity of fillet weld (not less than $.8L_{t.p.}$) = 1.2 SE x .707 T_{ph} x π(I.D.)
Allowable load per plug: = 1.5 L_p

Note: The value of "S" entering the above formulea must be taken at atmospheric temp.

$\frac{L_{t.p.}}{\text{number of plugs}}$ = total load per plug (which must not exceed allowable)

Riveted Joints. Use with shell plate over 5/8" thickness. See sheets for rivet data including allowable stress, inherent corrosion in heads etc. The rivets carry the entire load on the head.

Use swell neck rivets with over-size cone heads inside. The oversize to provide the required corrosion (See Sheet). Rivets are gunned or driven from both sides and standard button heads are formed.

Maximum diameter of rivets: Shop 1 1/8". Field 1"... Rivet holes are 1/32" larger in diameter with chamfer at both heads - 1/16" chamfer up to 1" ϕ rivets. 3/32" chamfer for rivets 1 1/16" ϕ & up.

Strength of Riveted Joint:

Unit length = P = pitch of 1 row of rivets n = no. of rivets in length 'P'

r_s = value of 1 rivet in single shear (See Sheet) d = diam. of rivet hole.

r_b = " " 1 " " bearing (" ") = (T-C) x d x bearing value of plate

1) Solid Plate: P x (T-C) x S. 'T' is thickness of shell or head whichever is less

2) Rivet Strength: (n x r_s) or (n x r_b) whichever is less.

3) Tearing along outer row of rivets: (P-d) x (T-C) x S

Joint efficiency (at least equal to 50% of longitudinal joint efficiency) = $\frac{(2)}{(1)}$ or $\frac{(3)}{(1)}$ whichever is less.

Edge Distance: Mininum = 1 1/4 d

Distance between rows: 1: p/d $\leq$ 4 minimum distance = 1 3/4 d

1: p/d $>$ 4 " " = 1 3/4 d + 0.1 (p-4d)

Bend line distance : minimum = 1/2 diam. of inside head after driving + 1/8".

Test Condition Check:

The joint efficiency based on uncorroded plate and 1½ times allowable stress at atmosphere temperature, must be at least equal to 50% of the longitudinal joint efficiency.

1) Solid Plate = P x T x 1.5 x S

2) Rivet Strength = 1.5 (nxr_s) or 1.5$(n \times r_b)$

3) Tearing = (p-d) x T x 1.5 x S

4) Joint efficiency $\frac{(2)}{(1)}$ $\frac{(3)}{(1)}$ whichever is less.

C. External Heads, with lap joint to shell, concaved side to pressure.

Thickness, T, determined from II a, is independent of shell T. Joint as per Fig 2 P 310 api-asme code. For shell plates up to 5/8" use plug welds. For shell plates 11/16" & up use rivets. Use formulea & methods under internal heads, above..

D. Conical Head or Reduction. (No code limitation on ratio of diameters of shell elements connected by a conical reduction.)

(a) Thickness: $t = \frac{p \times D_c}{2SE\ Cos.\&} + C$ or (b) $\frac{D + 100}{1000} + C$

Use larger value (a) or (b) but not less than 1/4" fully corroded.

(c) T.P. = $1\frac{1}{2} \times \frac{2\ SET\ Cos.\&}{D_m}$

D_c = largest I.D. + T

& = angle between side & long amis of cone.

Note = No reinforcing (equal to a pad) required on conical reduction. For T.P. use value of 2SE for atmospheric temperature.

VII Stress in Longitudinal Seam at Test Pressure.

Required only if Code inspected.

(a) Stress = $\frac{T.P. \times D_m.}{2T}$ Make calculation for each diam. & thickness of shell.

VIII Vessel Thickness to Withstand Test Pressure.

A Shell: $t_s = \frac{T.P. \times D_m}{3S_2}$ or $\frac{I.D. + 100}{1000}$ Use larger value.

B Heads: Ellipsoidal $t_s = \frac{T.P. \times D_m \times V}{3S_2}$ V = a factor = 1 for 2:1 heads) Fig 4 Code. ¶ W311. With 2:1 head, some T as shell, "t_S" will be same as shell and no calculation is required.

Dished $t_s = \frac{T.P. \times R\phi}{3S_2}$ $R\phi$ = Dishing radius + $\frac{T}{2}$

IX Reinforcing Plate (pad) Thickness.

Calculate theoretical thickness for both design and test conditions and select a commercial plate containing the larger of the two values.

Test condition thickness : $t_{rt} = 2\ t_s - T$ for all vessel elements.

Design condition thickness: $t_{rd} = 2\ (t-c)\ E + C-T$ (for all vessel elements except dished heads)

Design condition for dished heads only: $t_{rd} = 2\ (\frac{t-c}{\omega_1})\ E + C-T$ for ω_1 see II A.

Use greater value of either test or design condition and call it Tr. When $\frac{D+100}{1000}$ governs, or shells or heads are seamless omit E from formulea. Make a set of calculations for each tower element having openings subject to reinforcement. Minimum pad thickness 1/4". When t_{rt} or t_{rd} is substantially less than .25", investigate each conn. to see if pad can be omitted.

X Pad Sizes

A. Diameter. When useing pad thickness determined from IX the diameter is 2xI.D. of connection, if test pressure governs & 2(I.D. + 2C) if design governs.

B. Minimum Diameter. When T + Tr does not exceed 3/4" min. dia. pad = O.D. of neck + 1½" + 1/8" + 2(T + Tr)
When T + Tr exceeds 3/4" min. dia. pad = O.D. of neck + 1½" + 1/8" + 2 Tr

C. Pad Weld: (pad to shell, Alco practise, i.e. Pad diameters as given in ¶A above

Size of fillet weld = $\frac{t_{rt} \text{ or } t_{rd}}{C}$

Values of C	Steel	Stress Relieved	Not Stress Rel.
	Grade A	1.07	1.01
	Grade B	1.04	.98

For any one value of t_{rt} or t_{rd} one calculation will cover all pads, for diameters in accordance with ¶A. Pads of minimum diameter (¶B) are actually special ~~special~~ pads and if very thick, weld should be determined as for a special pad.

D. Special Pads: Area of required reinforcement $A_e' = I.D. \times t_{rt}$ for test condition or $(I.D. + 2C) \times t_{rd}$ for Design Conditions.

$$O.D.\ Pad = \frac{A_R}{\text{Desired thickness}} + D \quad \text{for design conditions or}$$

$$\frac{A_R}{\text{Desired thickness}} + I.D. \quad \text{for test conditions.}$$

E. Welds for Special Pads. (Pads to Shell)

$$\text{Size of Fillet Weld} = \frac{A_R}{K \times O.D.\ \text{of Pad.}}$$

Values Of K	Steel	Stress Relieved	Not Stress Relieved
	Grade A	.527	.506
	Grade B	.521	.490

F. Head Pads. For Code limitations of diameter see Sheet

G. Investigation of Pad Requirements:

Area of required reinforcement. Use formulea in ¶X, D. The only area available for reinforcements is in the nozzle neck = Y + area of welds.

Y = 2 times excess in neck times length of excess.
Excess in neck is wall thickness (N) minus hoop and corrosion: --

For test conditions (corrosion = 0) $= N - \left(\frac{I.D + 100}{1000}\right)$ or $N - \left(\frac{T.P. \times D_M}{3\ S_2}\right)$ Use Smaller Value.

For design conditions $= N - \left(\frac{D + 100}{1000} + C\right)$ or $N - \left(\frac{P \times D_m}{2\ S} + C\right)$ Use Smaller Value

Length of Excess: The limit of reinforcement beyond shell, measured along nozzle neck, is the smaller of the following - $2\frac{1}{2}$ (+ -C) or $2\frac{1}{2}$ (N-C) + pad thickness for design conditions. For test conditions this becomes $2\frac{1}{2}$ T or $2\frac{1}{2}$ N + pad thickness. Therefore the length of excess to be use in determining Y is: -

Length of Excess = the smaller of: $2\frac{1}{2}$ (+ - C) or $2\frac{1}{2}$ (N - C) for design conditions; $2\frac{1}{2}$ T or $2\frac{1}{2}$ N for test conditions

IF Y + weld area = area of required reinforcement no pad is required.

Pads are not required by api asme code for connections whose corroded inside diameters do not exceed 2".

Starting with smallest nozzle ingurstion, investigate progressively until a size is obtained which does require a pad. All larger nozzles of similiar type will require pads. Use judgement in investigation, I.E., if it appears that no pads will be required below the 10" size, select a nozzle around that size and proceed up or down, as indicated by result.

WEIGHTS

	Gross Weights	Deductions o/c of Corrosion
1. Shell (weight x mill average - 1 line for each element)	x x x	x x x
2. Heads (1 line for each different head)	x x x	x x x
3. Manholes (No of each size X weight)	x x x	x x x
4. Davits (Total No. X weight)	x x x	
5. Nozzles	x x x	x x x
6. Fixed Steel Trays or (Steel Supports for removable trays)	x x x	x x x
7. Baffles, Discs, Do-Nuts, Pans etc (Use 1 line for each diff. item)	x x x	x x x
8. Insulation Angles (No rings of _X" X" _"S @ # x length)	x x x	Total = C
9. Skirt (Size ℄ x length x weight x mill average) x x x		Weight To Be Used For Bolt Pull - W) =
10. Base Ring x x x		
11. Chairs No @ # each x x x		
12. Other Base Items x x x	x x x	Subtotal $ 2
	Subtotal $1	Corrosion - C
		Differenic = W 1

Keep All Figures in Columnar Alignment

(Note. Keep skirt & base separate as shown to permit adjustment after sizes are determined)

Insulation (State Kind & Thickness)
Shell x x x (In)
Heads x x x = x x x

Vapor Piping x x x (Take wind noments on all pipe listed in weights)

Other Piping x x x ⎤ x x x
Top Platform. ⎥ x x x
Wing Platforms ⎦ x x x

[35# per square foot. Wing platforms: Allow 15 ⊕ for 6 ϕ tower. 20 ⊕ for 8ϕ -25 ⊕ for 10ϕ and over (unless otherwise instructed.]

Subtotal $ 2 ← Use for Bolt Pull after deducting "C". See above

1/3 Water (1/3 x $\frac{\text{Wt-}H_2O}{\text{per foot}}$ x {Distance between B/L + .2 Diam.}

Removable Trays	x x x			
Caps & Troughs.	x x x			
Removable Internals.	x x x = Sum (T_R)		x x x	
		Sum Total	W 3	Use For Skirt & Base
2/3 Water (Twice above 1/3)			x x x	
		Total	W4	Calculations

Fire Proofing = F_R - x x x

(Note - Each sub-total ($ 1, $ 2, W3 & W4) is the sum of the preceeding sub totals + Intervening Figures)

Weights to appear on drawing

1) Tower empty without removal trays, caps, troughs & insulation) = Sub total $ 1
2) Tower empty (but with rem. trays, caps & troughs but without insulation) = $1 + T_R
3) Insulation & Fire Proofing In + F_p
4) Insulated tower full of water 2) + 3) + 3/3 Water

CYLINDRICAL VESSELS

CAPACITIES AND WEIGHT OF WATER PER FT.

231 cub." per gal. 8.3 # per gal.

Inside DIA. Ft. & In.	Inside DIA. Inches	Area Sq.Ft. or Vol-Cu.Ft. per Ft. Depth	Gallons per Ft. Depth	Weight Water lbs. per Ft. Depth	Inside DIA. Ft. & In.	Inside DIA. Inches	Area Sq.Ft or Vol-Cu.Ft. per Ft. Depth	Gallons per Ft. Depth	Weight Water lbs. per Ft. Depth
1'-0"	12	.7854	5.8752	49.0	9'-0"	108	63.617	475.89	3972
1'-3"	15	1.2272	9.180	76.6	9'-3"	111	67.201	502.70	4192
1'-6"	18	1.7671	13.219	110.3	9'-6"	114	70.882	530.24	4421
1'-9"	21	2.4053	17.993	150.2	9'-9"	117	74.662	558.51	4657
2'-0"	24	3.1416	23.501	196.1	10'-0"	120	78.54	587.52	4899
2'-3"	27	3.9761	29.743	248.2	10'-3"	123	82.516	617.26	5145
2'-6"	30	4.9087	36.720	306.4	10'-6"	126	86.59	647.74	5398
2'-9"	33	5.9396	44.431	370.8	10'-9"	129	90.763	678.95	5658
3'-0"	36	7.0686	52.877	441.3	11'-0"	132	95.033	710.90	5925
3'-3"	39	8.2958	62.057	517.9	11'-3"	135	99.402	743.53	6196
3'-6"	42	9.6211	71.971	600.6	11'-6"	138	103.87	776.99	6475
3'-9"	45	11.045	82.620	689.5	11'-9"	141	108.43	811.14	6759
4'-0"	48	12.566	94.003	784.5	12'-0"	144	113.10	846.03	7050
4'-3"	51	14.186	106.12	885.6	12'-3"	147	117.86	881.65	7347
4'-6"	54	15.904	118.97	992.8	12'-6"	150	122.72	918.00	7650
4'-9"	57	17.721	132.56	1106.2	12'-9"	153	127.68	955.08	7959
5'-0"	60	19.635	146.88	1225.7	13'-0"	156	132.73	992.91	8274
5'-3"	63	21.648	161.93	1351.4	13'-3"	159	137.89	1031.5	8608
5'-6"	66	23.758	177.72	1482.5	13'-6"	162	143.14	1070.8	8935
5'-9"	69	25.967	194.25	1621.0	13'-9"	165	148.49	1110.8	9270
6'-0"	72	28.274	211.51	1765	14'-0"	168	153.94	1151.5	9608
6'-3"	75	30.680	229.50	1915	14'-3"	171	159.48	1193.0	9956
6'-6"	78	33.183	248.23	2072	14'-6"	174	165.13	1235.3	10308
6'-9"	81	35.785	267.69	2234	14'-9"	177	170.87	1278.2	10667
7'-0"	84	38.485	287.88	2402	15'-0"	180	176.71	1321.9	11031
7'-3"	87	41.282	308.81	2577	15'-3"	183	182.65	1366.3	11403
7'-6"	90	44.179	330.48	2758	15'-6"	186	188.69	1411.5	11779
7'-9"	93	47.173	353.88	2945	15'-9"	189	194.83	1457.4	12163
8'-0"	96	50.265	376.01	3138	16'-0"	192	201.06	1504.0	12552
8'-3"	99	53.456	399.88	3337	16'-3"	195	207.39	1551.4	12947
8'-6"	102	56.745	424.48	3542	16'-6"	198	213.82	1599.5	13348
8'-9"	105	60.132	449.82	3754	16'-9"	201	220.35	1648.4	13756

MINIMUM SHELL THICKNESS OF UNFIRED PRESSURE VESSELS, FABRICATED UNDER PAR. U-69 OF THE A.S.M.E. CODE AND OF A.S.T.M. A70-36 OR A.S.M.E. S-1 FLANGE OR FIRE BOX QUALITY STEEL.

FORMULA: Min. Shell Thick. = $\frac{\text{(Working Press.)(Outside Radius)}}{\text{(11,000)(.80) plus (Working Press.)}}$

The following constants may be used to determine shell thicknesses which are not shown. Multiply the constant "K" by the Outside Radius and the result is the minimum shell thickness required.

W. P.	"K"	W. P.	"K"
80#	.009009009	140#	.01565995
100#	.011235955	150#	.01675977
100.8#	.011324830	175#	.01949861
125#	.014005602	200#	.02222222

O. D. SHELL	80#	100#	100.8#	125#	140#	150#	175#	200#
12"	.05405	.06746	.06795	.08403	.09396	.10056	.11700	.13333
14"	.06306	.07865	.07927	.09804	.10962	.11732	.13649	.15555
16"	.07207	.08990	.09060	.11205	.12525	.13408	.15599	.17777
18"	.08108	.10112	.10192	.12605	.14094	.15084	.17549	.20000
20"	.09009	.11236	.11325	.14006	.15660	.16760	.19499	.22222
22"	.09910	.12360	.12458	.15407	.17226	.18436	.21449	.24444
24"	.10811	.13483	.13590	.16807	.18792	.20112	.23399	.26666
30"	.13514	.16854	.16987	.21008	.23490	.25140	.29248	.33333
36"	.16216	.20225	.20385	.25210	.28188	.30168	.35098	.40000
42"	.18919	.23596	.23782	.29412	.32886	.35196	.41947	.46666
48"	.21622	.26966	.27180	.33613	.37584	.40224	.46798	.53333
54"	.24324	.30337	.30577	.37815	.42282	.45252	.53647	.60000
60"	.27027	.33708	.33975	.42017	.46980	.50280	.58496	.66666
66"	.29730	.37079	.37372	.46219	.51678	.55308	.64346	.73333
72"	.32432	.40449	.40769	.50420	.56376	.60336	.70196	.80000
78"	.35135	.43821	.44167	.54622	.61074	.65364	.76046	.86666
84"	.37838	.47191	.47564	.58824	.65772	.70392	.83895	.93333
90"	.40541	.50562	.50962	.63025	.70470	.75419	.87744	1.00000
96"	.43243	.53933	.54359	.67227	.75168	.80448	.93596	1.06666
102"	.45946	.57304	.57757	.71429	.79866	.85475	.99443	1.13333
108"	.48649	.60672	.61154	.76631	.84564	.90504	1.07394	1.19999
114"	.51352	.64045	.64552	.79832	.89262	.95531	1.11142	1.26666
120"	.54054	.67416	.67949	.84034	.93960	1.00560	1.16992	1.33333

The above tables may be checked using the formulas shown below. The "Maximum Stress" must always be 8800 pounds or less and the "Bursting Pressure" must be five (5) times the working pressure or less.

Maximum Stress = $\frac{\text{Inside Radius Of Tank (Working Press.)}}{\text{Shell Plate Thickness}}$

Bursting Press. = $\frac{\text{55,000 (Shell Plate Thickness) .80}}{\text{Inside Radius Of Tank}}$

WEIGHT OF API-ASME DISHED HEADS (From Tangent or Bend Line)

.935 x D^2	DIA Ft-In	THICKNESS - INCHES 1/4"	5/16"	3/8"	7/16"	1/2"	9/16"	5/8"	11/16"	3/4"	13/16"	7/8"	1"	1 1/8"	1 3/16"	1 1/4"
2.250	1'-6"	22	27	32	38	43	48	54	59	64	70	75	86	96		107
3.74	2'-0"	38	48	58	67	77	86	96	105	114	125	134	154	172		191
6.32	2'-6"	60	75	90	105	110	135	150	164	179	194	208	250	268		298
8.41	3'-0"	87	108	129	150	172	194	215	236	258	279	300	345	388		430
12.96	3'-6"	108	148	176	206	236	266	295	324	354	384	412	474	528		588
14.96	4'-0"	154	193	230	278	306	345	385	420	460	500	535	615	690		765
19.78	4'-6"	196	245	295	345	390	440	490	535	585	635	680	780	875		970
23.375	5'-0"		300	360	420	480	540	600	660	720	780	840	960	1080		1200
28.783	5'-6"			435	505	585	655	730	800	870	945	1015	1070	1310		1450
33.66	6'-0"			515	605	690	780	865	945	1080	1120	1200	1380	1540		1720
39.5	6'-6"			610	710	810	910	1010	1110	1210	1310	1410	1610	1810		2010
45.81	7'-0"			705	820	940	1060	1075	1290	1410	1520	1640	1870	2100		2340
52.59	7'-6"			805	940	1080	1215	1350	1480	1610	1750	1880	2160	2410		2680
59.84	8'-0"			920	1070	1230	1380	1540	1690	1840	1980	2140	2460	2780		3800
67.55	8'-6"			1040	1210	1390	1570	1740	1810							
75.78	9'-0"							1930	2160							
84.84	9'-6"					1720				2600						
93.5	10'-0"						2150						3850			
103.08	10'-6"															
113.13	11'-0"								3200	3500						
123.65	11'-6"												5100			
134.64	12'-0"										4500		5500			
146.04	12'-6"								4170							
158.00	13'-0"								4503							
167.50	13'-6"															
184.00	14'-0"															
197.00	14'-6"															
211.50	15'-0"								6000							
	weight steel per sq.ft.	10.2	12.75	15.3	17.85	20.4	22.95	25.5	28.5	30.6	33.5	35.5	40.8	45.9	48.5	51.0

SURFACE AREA (EXTERIOR) OF API-ASME DISHED HEADS = $.935\ D^2$ = SQ. FT.

FOR ELLIPTICAL HEADS USE .33 FOR 2:1 RATIO

WEIGHT CYLINDRICAL VESSELS

Per 1 ft. Depth

(Actual Theor. Wgts.)

I.D. Ft.-In.	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
1'-0"	16.4	24.6	32.8	41.3	49.6	58.2	66.8	75.5	84.2	93.5	102	111			
1-3	20.4	30.6	40.8	51.3	61.6	72.2	82.8	93.5	104	116	126	137			
1-6	24.4	36.6	48.8	61.3	73.6	86.2	98.8	112	124	138	150	163			
1-9	28.4	42.6	56.8	71.3	85.6	100.2	115	130	144	160	174	189			
2-0	32.4	48.6	64.8	81.3	97.6	114	131	148	164	182	198	215			
2-3	36.4	54.6	72.8	91.3	110	128	147	166	184	204	222	241			
2-6	40.4	60.6	80.8	101	122	142	163	184	205	226	246	267			
2-9	44.3	66.6	88.8	111	134	156	179	202	225	248	270	293			
3-0	48.4	72.6	96.8	121	146	170	195	220	245	270	294	319			
3-3	52.4	78.6	105	131	158	184	211	238	265	292	318	345			
3-6	56.4	84.6	113	141	170	198	227	256	285	314	342	371			
3-9	60.4	90.7	121	151	182	212	243	274	305	336	366	397			
4-0	64.4	96.7	129	161	194	226	259	292	325	358	390	423			
4-3	68.4	103	137	171	206	240	275	310	345	380	414	449			
4-6	72.4	109	145	181	218	254	291	328	365	402	438	475			
4-9	76.4	115	153	191	230	268	307	346	385	424	462	501			
5-0	80.4	121	161	201	242	282	323	364	405	446	486	527			
5-3		127	169	211	254	296	339	382	425	468	510	553			
5-6		133	177	221	266	310	355	400	445	490	534	579			
5-9		139	185	231	278	324	371	418	465	512	558	605			
6-0		145	193	241	290	338	387	436	485	534	582	631			
6-3			201	251	292	352	403	454	505	556	606	657			
6-6			209	261	304	366	419	472	525	578	630	683			
6-9			217	271	316	380	435	490	545	600	654	709			
7-0			225	281	338	394	451	508	565	622	678	735			
7-3			233	291	350	408	467	526	585	644	702	761			
7-6			241	301	372	422	483	544	605	666	726	787			
7-9			249	311	384	436	499	562	625	688	750	813			
8-0			257	321	386	450	515	580	645	710	774	839			
8-3			265	331	398	464	531	598	665	732	798	865			
8-6			273	341	310	478	547	616	685	754	822	891			

Weight Cylindrical Vessels (con't)

I.D. Ft.-In.	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
8-9			281	351	322	492	563	634	705	776	846	917			
9-0			289	361	434	506	579	652	725	798	870	943			
9-3			297	371	446	520	595	670	745	820	894	969			
9-6			305	381	458	534	611	688	765	844	918	995			
9-9			313	391	470	548	627	706	785	866	942	1021			
10-0			321	401	482	562	643	724	805	888	966	1047			
#/□'	5.10	7.65	10.20	12.75	15.3	17.85	20.4	22.95	25.5	28.05	30.6	33.15	35.7	38.25	40.8
" 71	16.05	24.10	32.10	40.10	48.10	56.10	64.2	72.0	80.2	88.2	96.2	104.0	112.1	120.2	128.4
Feet Thick	.0104	.01563	.0208	.026	.03125	.0365	.0417	.04688	.0521	.0573	.0625	.0677	.0729	.0781	.0833
Diff. per in.						4.67	5.34	6	6.75	7.35	8	8.66			
Diff. per ft.						56	64	72	80	88	96	104			

Note: For different diams. than those given above take diff. per inch or foot and add to nearest diam. in table: I.E. 15'-4" diam. = $\frac{1}{2}$" tk. = 643 + (5 x 64) + (4 x 5.34) = 984#.

WEIGHTS

Instructions For Calculating Tower Weights

1. HEADS:- Add to required min. head thickness the "Thinning Allowance" from Table I.

SIZE OF DISC: Ellipsoidal Head, 2:1 Ratio:-(1.21 x 1.0) 2 S.F. + Plate thickness. F & D Head:- (1.04 x O.D.) 2 S.F.+ 2/3 K.R.

WEIGHT ALLOWANCE:-Disc is cut from rectangle. Increase weight by constant from Table III.

2. SHELL . LENGTH OF SHELL: - Distance between extreme girth seams. (Not B.L.)

WEIGHT ALLOWANCE:- Multiply total weight by constant from Table II.

3. NOZZLES & MANHOLES:- Add to M.H. weight, davit weight

8. PIPING:- Include weight of all piping for which Wind Moments are taken- (usually only vapor line). Vapor lines usually not insulated. Weight:- 110% weight of bare pipe in even pounds. Length:- ½ tower height.

9. LADDERS:- Cage is 7' shorter than ladder. With top platform, ladder height is same as centroid of top platform. Without top platform ladder height is top bend line, (unless engineers data is contrary-wise). Weight:- Ladder 6.5 #/foot - Cage 10.5 #/foot.

PLATFORMS:- Weight:- 50 #/lineal foot. Wing platforms, from 1/8 to 1/4 circumference of tower, depending on diameter. Top platform 1 foot longer than O.D. over insulation.

10. INSULATION:- Shell:- Weight per lineal (of tower from 'opus') x distance between B.L's. Heads:- Determine square feet of insulation, using formulea for head discs, but substuiting mean diameter of shell insulation for 1.0 (or O.D.) given in disc Formulea.

WATER:- Weight per lineal foot from "Opus" x distance between bend lines. (Shell) Head, Ellipsoidal:- Weight per lineal foot of shell x .425 height of head. Head, F & D:-

FIREPROFFING:- Outside Fireproofing up to B.L. Inside less % head & insulation.

TABLE I. THINNING ALLOWANCE FOR HEADS.						
quired Mininum Head Thickness	under 1"	1" to 2"	2" to 3"	3" to 3 3/14	3 3/4 to 4½	4½"up
d for Thinning	1/16	1/8	1/4	3/8	1/2	3/4

TOWER DEFLECTION

F = Max deflection at top of tower or superstructure = fu + fc

fu = Max deflection at top of tower or superstructure due to uniform load.

fc = Max deflection at top of tower or supersturcture due to concentrated load.

Yu & Yc = Deflection at "x" inches below top due to uniform & concentrated loads.

W = Uniform wind load = Area of tower elements in sq. ft. x wind pressure in pounds.

P = Concentrated load. (at top of tower = area of superstructure x wind pressure in lbs.

E = Modulus of elasticity for operating temperature. (See Curve I)

L = Height in inches.

I = Moment of inertia of fully corroded shell (or skirt)

D = O.D. of shell or skirt. I (for annulus) = $\pi/64\ (D^4-d^4)$ = $.049087\ (D^4-d^4)$

d = I.D. of corroded shell or skirt.

α = Angle of inclination to horizontal of any tray. $\alpha = \tan^{-1}\alpha u + \tan^{-1}\alpha c$

h = Distance in inches between high & low sides of seal plate.
Tanx x I.D. of tower

$fu = WL^3/8EI$ $\qquad$ $fc = WL^3/3EI$

$Tan.\alpha_u = W/6EIL\ (L^3-x^3)$ Due to uniform load.

$Tan.\alpha_f = W/2EI\ (L^2-x^2)$ Due to concentrated load.

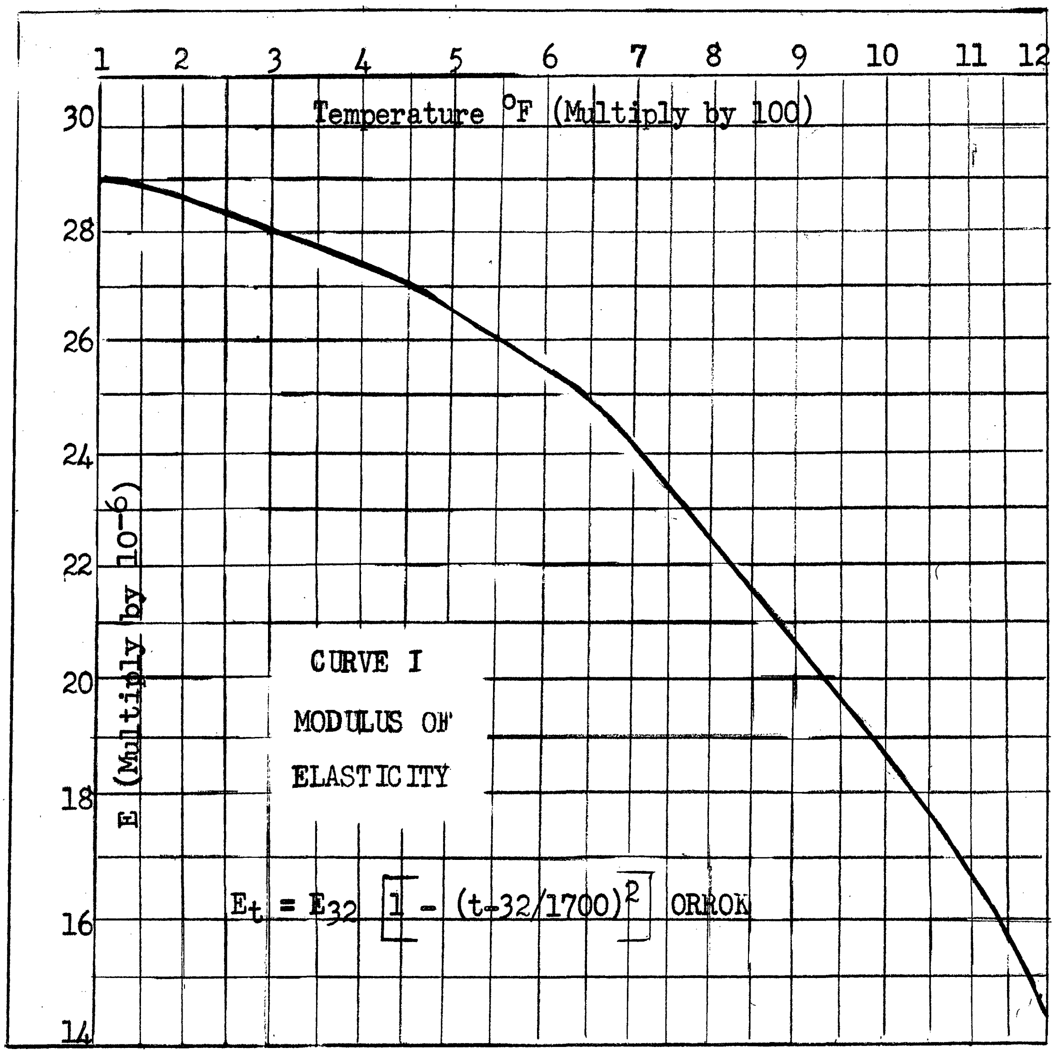
$Yu = W/24EIL\ (x^4-4L^3x+3L^4)$ Due to uniform load.

$Yc = W/6EI\ (2L^3-3L^2x+x^3)$ Due to concentrated load.

Note: $Tanx = d(fy)/\alpha x$

TABLE II WEIGHT ALLOWANCE

Plate Width → / Plate Thickness ↓	Under 48"	48 Under 60	60 Under 72	72 Under 84	84 Under 96	96 Under 108	108 Under 120	120 Under 132	132 Under 144
Under 1/8"	9	10	12	14					
1/8" " 3/16	8								
3/16 " 1/4	7								
1/4 " 5/16	6						14	16	19
5/16 " 3/8	5							14	17
3/8 " 7/16	4½							12	18
7/10 " 1/2	4							10	13
1/2 " 5/8	3½								11
5/8 " 3/4	3								9
3/4 " 1	2½								8
1" & Over	2½	2½	3	3½	4	4½	5	6	7



1 2 3 4 5 6 7 8 9 10 11 12
Temperature °F (Multiply by 100)
30
28
26
24
22
20
18
16
14
E (Multiply by 10-6)
CURVE I
MODULUS OF
ELASTICITY
Et = E32 [1 - (t-32/1700)2] ORROK

A two section tower, shown in Figure 1, is loaded by a concentrated force, P#, acting at the free end, and by a total load, W#, uniformly distributed over the length L.

Notation:

I_o = Moment of inertia, upper section (in^2)

I_1 = Moment of inertia, lower section (in^2)

$t = I_o/I_1$ $\qquad m = 1/L$

E = Modulus of elasticity, consultesr - 270

a, b, and c = coefficients, consult charts.

1 and L = lengths in inches

Deflection at free end due to P alone:

$$\Delta P = b\ PL^3/3EI_o \quad \ldots\ldots\ldots\ldots\ 1)$$

Deflection at free end due to W alone:

$$\Delta W = c\ WL^3/8EI_o \quad \ldots\ldots\ldots\ldots\ 2)$$

Rotation at free end due to P alone:

$$\delta P = a\ PL^2/2EI_o \quad \ldots\ldots\ldots\ldots\ 3)$$

Rotation at free end due to W alone:

$$\delta W = b\ WL^2/6EI_o \quad \ldots\ldots\ldots\ldots\ 4)$$

<u>Notes</u>: 1. For a single section tower use a = b = c = 1 in above equations

2. According the principle of superposition the total deflection (or rotation) under combined loads is equal to the sum of the partial deflections (or rotations).

3. The actual rotations shall always be sufficiently small to warrant the: <u>$\tan\delta = \delta = \sin\delta$</u> Relation.

4. Difference in elevation of diametrally opposite points at top $K = (\delta p\ \delta w)$ x dia.

A three section tower is shown schematically, in figure 2, loaded as before.

Notation:

$I_{.}$, I_1 and I_2 = moments of inertia of the respective sections