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United States Coast Guard (

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NAVIGATION AND VESSEL INSPECTION CIRCULAR NO. 5-89
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Subj: Guidelines for Nondestructive Testing of Pressure Vessel Type Cargo Tanks Aboard Tank Barges

1. PURPOSE. This Circular explains minimum recommendations for satisfying Pressure Vessel type Cargo Tank (PVCT) Nondestructive Testing (NDT) requirements published in the Federal Register as part of Parts 38, 98 and 151 of 46 CFR. This Circular should be used when preparing NDT proposals for submission to the Officer in Charge, Marine Inspection (OCMI) in compliance with applicable regulations.

2. BACKGROUND.

   a. Brief history of regulatory project. In response to an industry request in 1981, the Coast Guard initiated a project to review existing inspection requirements for PVCTs. Revised regulations extending the internal examination interval for most cargoes presently carried in PVCTs were recently published. These regulations will affect about 2/3 of all PVCTs.

   b. Reasons for a regulatory NDT requirement.

      (1) The most important reason for requiring NDT on PVCTs is to determine the condition of the tank and ensure that it is acceptable for its present service.

      (2) Periodic NDT on PVCTs thirty years old or older was required to permit extending internal examination intervals from 4 or 8 years to 10 years for most tanks.

      (3) Design life of these tanks is estimated to be 20 to 30 years. Actual service life is unknown because: of lack of research data about the actual type, magnitude, and number of cycles of stress encountered in marine service; the working pressure is sometimes significantly less than the design pressure; and, shore tanks which have experienced failures have not been subjected to the additional loads encountered in marine service. These loads include bending and torsion, caused by bending and twisting of the hull and transmitted to the tank through the saddles-, vibration, longitudinal forces caused by liquid sloshing in the tank, and impacts due to minor collisions. Not having precise information about actual loading induced stresses and the number of cycles which would be experienced, industry may have "over designed" the PVCTs which are now in service.

      (4) Surface cracking due to fatigue and/or environmental effects is not visible to the naked eye in the initial stages and sometimes escapes detection until failure occurs.

(5) Fatigue life cannot be accurately predicted.

(6) Fatigue cracking can be detected by routine inspection using NDT.

3. DISCUSSION.

a. NDT Requirements.

(1) On all insulated FVCTs, the owner is required to remove insulation as determined by a Coast Guard marine inspector or, alternatively, to conduct NDT for thickness determination as accepted by the inspector, at each internal exam, regardless of age or internal exam interval.

(2) 46 CFR 38.25-1(a), 98.25-95(a), and 151.04-5 require NDT as prescribed by sections 38.25-3(a), 98.25-97(a) and 151.04-7(a) (respectively) at each internal exam of PVCTs 30 years old and older having a 10 year internal exam period. NDT is not required for PVCTs with an internal exam period of less than 10 years.

(3) Sections 38.25-3, 98.25-97 and 151.04-7 require all NDT methods and procedures to meet the standards of Section V of the ASME Boiler and Pressure Vessel Code, and all personnel performing NDT to meet the qualifications of the American Society for Nondestructive Testing (ASNT) "Recommended Practice for Nondestructive Testing Personnel Qualification and Certification" (SNT-TC-lA (1988)). Both are now incorporated by reference into the regulations.

b. Description of Cargo Tanks.

(1) Except for a small number of specialty ships carrying LFG, LNG and Ammonia, most PVCTs are cylindrical tanks carried on barges. In 1988, 187 barges were identified with two to six tanks on each barge. PVCTs vary widely in size; from 90 to 270' in length, and from 12 to 20' in diameter. Skin thickness ranges from .5 to 1.75 inches. Tank ages range from 9 to 40 years; refrigerated anhydrous ammonia barge tanks range from 22 to 29 years. Cargoes required by regulation to be carried in PVCTs include LFG, Anhydrous Ammonia, Propylene Oxide, Chlorine, etc. Some products, such as Butyl Acrylate, Ethylene Dichloride, etc., are voluntarily carried in PVCTs. Even though PVCT use may be voluntary, regulatory requirements still apply.

(2) For purposes of this NVIC, PVCTs are categorized into two classes: Insulated - low pressure (3 - 5 psi working pressure, 10 - 75 psi design pressure), refrigerated tanks, usually carrying NH_3; or Uninsulated - both unpressurized and pressurized (carrying cargoes at pressures as high as 265 psi) tanks, at ambient temperature.

(3) On refrigerated tanks insulation is four to six inches thick, or thicker, and usually incorporates the use of a vapor barrier to prevent atmospheric moisture from condensing on the cold tanks, which could cause corrosion and insulation deterioration. Many of these tanks also have sheet metal rain shields to prevent rain from getting into the insulation for the same reasons. When the insulation/vapor barrier/rain shield is applied, great care is taken to lock out as

much atmospheric moisture as possible. If the barrier is later breached due to repairs or a leak near a nozzle or fitting, the vapor barrier may work in reverse holding moisture in the insulation and/or near the skin.

(4) PVCTs are supported in saddles, or cradles, spaced 12 - 20' apart and are usually, but not always, mounted longitudinally (Figure 1). The saddles may extend around the tank 120^0 or 180^0 (Figure 2A and 2B, respectively). Wear plates are sometimes used to protect the tank (Figure 3A). Mounting blocks of wood are often used on insulated PVCTs to prevent heat loss (Figure 3B). Note: all Figures are in enclosure (2).

(5) PVCT construction is typically of formed 8 by 20' steel plates manufactured into a large cylinder. Hemispherical heads formed of plate one and one half to two times thicker than the shell plate are attached to the shell of the cylindrical body with circumferential welds. The heads are usually constructed by one of two means: (1) out of a set of orange peel sections which meet in a small circular section in the center of the head, known as a dollar plate (Figure 4). Dollar plates can be as large as 10' in diameter, but are typically 18" or less; or, (2) flanged and dished, where the head is formed out of one plate (or sometimes two plates joined together at a seam) and joined to the shell by means of a short (typically 12") collar (or flange). Flanged and dished heads do not have dollar plates.

(6) In addition to the unique loads encountered in marine service, PVCTs are subjected to the normal loads of pressurized tanks: expansion and contraction due to pressure when loaded and unloaded; and expansion and contraction due to refrigerated cargoes. This expansion and contraction causes an effect known as ballooning. Ballooning occurs at the abrupt termination of the support saddles (the ends of which are known as saddlehorns) when the shell is no longer stiffened against expansion. Figure 5 shows ballooning in an exaggerated manner. This ballooning causes increased stress at the saddlehorns which is a "hard spot". The use of 180^0 saddles decreases the ballooning effect.

(7) Stiffener rings, also known as support rings, also decrease the ballooning effect because of the 360^0 support which they give the shell. Stiffener rings allow the use of thinner shell plate, which simplifies construction and reduces the initial cost. Stiffener rings have a shape with an I, T or H-beam cross section, are approximately one foot deep, and can be internal or external. They are generally mounted internally to make the outer diameter of the tank smaller. On insulated tanks they are mounted internally to present a smooth exterior surface for insulation and to keep from acting as a "warming fin" which would heat up refrigerated cargoes. On insulated tanks the stiffener rings are usually lined up in way of the saddles. Uninsulated tanks have a wider variety of construction and this may not necessarily be so.

c. Determination of Likely Failure Mechanisms

(1) Fatigue - normally results from cyclic (i.e., repeated or fluctuating) stress at a level quite a bit less than the yield strength of the material. The cyclic stressing initiates and propagates a crack. Failure occurs when the applied load exceeds the strength of the increasingly weakened part. Fatigue cracking starts as surface cracking, and can initiate on the exterior or interior surfaces of a PVCT, or from

discontinuities in the metal or weldment. Fatigue cracks start out microscopic in size and are normally undetectable by unassisted visual exam.

(2) Environmentally Assisted Cracking - such as stress-corrosion cracking (SSC), hydrogen embrittlement (or attack), carburization, chloridization, erosion, etc., are mechanical-environmental failure modes caused by simultaneous exposure to a mild chemical environment and tensile stress well below the yield strength of the material. Due to the combined effect of stress and corrosion, initiation and subsequent propagation of cracks to the point of failure occurs more rapidly than it would if the effects were just additive. SSC is of particular concern. Fine cracks can penetrate deeply with little or no corrosion on the surface and no other visible signs.

(3) Crack Initiation Points - Fatigue and environmentally assisted cracks normally form at points of maximum local stress and minimum local strength. Factors which affect this are design, shape, load, material and workmanship. These factors are known as stress raisers or stress concentrations. Preexisting cracks or other surface discontinuities may act as a site for initiation of SCC, which can exacerbate fatigue cracking or other problems. Crack initiation factors applicable to PVCTs are:

(a) Structural discontinuities and changes in contour or section - stress concentrations such as section changes, sharp corners, threads, holes, etc. Examples include saddles, saddlehorns, stiffener rings, weld intersections, plate mismatch, sharp angles at fillet weld toes, nozzle penetrations, etc. Structural discontinuities are sometimes referred to as "hard spots" because of an abrupt change in material or structural reinforcement which increases stiffness or strength and concentrates stress/strain in a particular area.

(b) Cyclic loading - machinery (i.e., cargo pump) vibrations; thermal loading as a result of expansion and contraction when heated or cooled; pressure loading from two sources -pressurized cargoes and hydrostatic loading which may cause ballooning at tank supports; and, residual construction stresses.

(c) Material and workmanship defects - on the surface, or subsurface: inclusions; delaminations; porosity; weld undercut; incomplete fusion and incomplete penetration as a result of construction, but which were not large enough or in sufficient concentrations to be cause for rejection at time of construction; scratches; and, fretted areas (where the metal is worn away to form a pattern by rubbing or chafing).

(d) Environmental effects - attack by chlorides in cargo or atmosphere (including gaseous chlorine and salt air), and attack by ammonia vapor and/or liquid. Stress raisers can also be caused by a corrosive environment.

d. Identification and Location of the Critical Areas of FVCTs. The following critical areas are listed in the same order as in TABLE I in enclosure (1). (TABLE I applies only to tanks which are 30 years old or older.)

(1) Fittings. This term refers to any penetration of or attachment to a PVCT, and includes hatches, pump sumps, pump mounts, pump drive shaft tunnels, penetrations and nozzles of cargo fill and discharge lines, safety relief valves, and gauging tubes, etc. Cracks can initiate on the inside or outside surfaces within a few inches of these areas, and in particular from the fitting weldments. The most critical fittings are those subject to vibration and/or cargo flow, and the fittings five inches or larger in diameter. This includes cargo pump penetrations, sumps, and mounts, cargo fill and discharge lines, and manholes. Table I recommends that these important fittings be tested at each internal examination (every ten years), and that 50% of the remaining small diameter fittings be tested. At the next internal exam the last 50% of the small diameter fittings should be tested.

(2) Saddlehorns, or areas located near the upper tips of the saddles, on both sides of a PVCT. Cracks will usually appear on the exterior surfaces first, because of the "hard spot" created by the relatively abrupt ending of the saddle in the saddlehorn area. Use of 18O~ saddles reduces this tendency. Use of stiffener rings will further reduce this tendency to the point where the likelihood of interior and exterior cracks is approximately equal.

(3) Head to shell welds (circumferential). These welds may have residual stresses due to constraints placed on the joints during fit-up and welding, or mismatch of material strength. Cracks can initiate on the inside or outside surfaces. Flanged and dished heads will have two circumferential welds, while heads of dollar plate construction will have one.

(4) Circumferential and longitudinal weld intersections. "T" intersections may have residual stresses due to constraints placed on the joints during fit-up and welding, or mismatch of material strength. Cracks can initiate on the inside or outside surfaces. Cross or “X” intersections are not good practice and will not usually be found. If an "X" intersection is found, it should definitely be one of the intersections checked with NDT.

(5) Dollar plate. May also have residual stresses due to constraints placed on the joints during fit-up and welding, or mismatch of material strength. Cracks can initiate on the inside or outside surfaces. The larger the dollar plate is, the lower the effect of any locked in stresses. The recommended guidelines will mean nearly 100% of smaller dollar plates need to be tested, but only 50% of the weld area in larger ones.

(6) Stiffener ring welds (if any). These are non-load bearing continuous or intermittent fillet welds which serve only to attach the stiffener to the shell but are subject to stress as the PVCT undergoes strain. Cracks which start there can spread into the metal of the shell. For insulated tanks, where stiffener rings coincide with saddle locations, most of the TABLE I NDT requirement can be met by testing the fillet welds near the saddlehorns at the same time saddlehorns are being tested from the interior. Uninsulated tanks will require additional effort if stiffener rings do not coincide with saddles..

Table I recommends that 5% of these welds be tested every ten years. Most stiffener rings have two circles of the fillet welds, one on each side of the stiffener ring. It is intended that 5% of the fillet weld area on each of the two circles of each stiffener ring be tested.

e. Recommended NDT for Thickness Determination - Applicable to All Tanks of All Ages.

(1) 46 CFR 38.25-1(a)(3), 98.25-95(a)(2) and 151.04-5(c)(l) require the owner to remove tank insulation as required by a marine inspector at the time an internal examination is conducted. This requirement applies to all tanks regardless of age, and not just to tanks thirty years old or older. In lieu of this insulation removal the owner/operator may conduct NDT for thickness determination. The OCMI may want the owner to make this request in writing. If insulation is not removed, Straight Beam Ultrasonic Testing (SBUT) for thickness should be done in accordance with 3.f.(2)(c) below.

(2) The primary reasons for removing insulation are to check the exterior skin of the tank for corrosion and pitting due to water vapor condensation and/or rain shield and vapor barrier leakage, and to check the condition of the insulation. There are arguments pro and con for insulation removal. The biggest reason for removal is to allow a first hand visual look at the condition of the tank. It is felt that corrosion and insulation damage will be most likely to occur in the lower one third of the tank because condensation will run down the sides and soak into the insulation where it will be held for long periods of time. Other possible condensation collection points include areas in way of fittings which penetrate the insulation and vapor barrier. On the other hand, industry reports little or no problems with rain leakage to the skin of tanks and many feel any condensation which occurs, or water which might penetrate the insulation, will immediately be frozen in place by the low temperature cargo and not cause any problems. An informal Coast Guard survey in 1988 determined that this may be true, because there have been few problems with PVCT corrosion in the past. However, possible corrosion and deterioration of insulation cannot be ruled out.

(3) Before requiring any insulation removal, the following criteria should be considered:

(a) the external condition of rain shields, vapor barriers, and insulation;

(b) evidence of running rust coming from beneath the insulation;

(c) age of the insulation;

(d) results of last known insulation removal, if any; and

(e) results of last NDT, if any.

(4) It is anticipated some insulation will be removed by the owner/operator approximately once every 20 years for maintenance and/or replacement. Owners should take advantage of any insulation removal and request a Coast Guard inspector to verify the condition of the tank and insulation. This will prevent unnecessary insulation removal at a later date.

f. Recommended NDT on 30 Year Old Tanks. Methods, procedures and locations to be used for NDT required by regulation are shown in TABLE I in enclosure (1). These are to be done at ten year interval internal exams on PVCTs 30 years of age or older. TABLE I has separate columns for recommended NDT methods to be used on uninsulated and insulated PVCTs. Insulation need not be removed from insulated tanks in order to conduct NDT to provide enough information to make a determination of its structural adequacy. Special gas freeing for NDT will not normally be necessary because the NDT will usually be done at credit internal exams when the cargo tank(s) will already be gas free. No one should enter a PVCT, or any other cargo tank or closed up space, without ensuring that it is gas free, safe for workers. The following comments amplify TABLE I.

(1) Uninsulated PVCTs.

(a) Conduct a visual inspection of external and internal surfaces, and saddles for corrosion, mechanical damage, and visible cracking in critical areas. Take particular note of internal and external areas in way of internal stiffener rings, if the PVCT is so equipped. While conducting this exam take into account the effects (corrosion, pitting, etc.) cargo, cargo vapors, and cargo contamination may have on the tank.

(b) The preferred NDT method for detection of small surface cracks is Wet Fluorescent Magnetic Particle Testing (WFMPT). It should be used to examine all critical areas specified in TABLE I. Remember that many of the cracks will be so small as to be invisible to the naked eye, but will show up under the UV light. Eddy Current Testing (ECT), Shear Wave Ultrasonic Testing (SWUT), and Acoustic Emission Testing (AET) are also acceptable to the Coast Guard. Dye Penetrant Testing (DPT) is acceptable in some instances, but does not generally detect small enough cracks for this application, and is a secondary choice in place of WFMPT for interior surfaces. Appropriate surface preparation, as recommended in ASNT, ASME, and other industry guidelines, should be done before using any NDT method.

One half of the required amount of NDT should be done on the exterior of the tank and one half should be done on the interior. For example, Table I requires 50% of the saddlehorns to be inspected. One half of these, or 25% of the total number of saddlehorns supporting the tank, should be examined using WFMPT from the exterior, and 25% using WFMPT from the interior.

(c) Critical areas on the interior top of a tank should be tested. When examining areas at the top of the tank from the interior, care should be taken to look for accelerated corrosion commonly found at the air/vapor interface of tanks carrying corrosive cargoes.

(d) NDT will usually be required by the OCMI or inspector to determine the thickness or condition of the shell. Use of SBUT for spot checking thickness will be all that is normally required for uninsulated tanks and can be done from the exterior or interior. The spot UT should be done in locations where there is evidence of damage, isolated corrosion or pitting, or if there is any reason to suspect the shell has worn thin.

(e) None of these suggested guidelines limit the authority of the OCMI and/or marine inspector to require any NDT which is considered necessary in their professional judgment. Problems found during the examination will be fully investigated to determine the nature and extent of the problem, and a course of action that allows safe operation of the PVCT.

(2) Insulated PVCTs.

(a) Conduct a visual inspection of internal and unlagged external surfaces and saddles for corrosion, mechanical damage to tank or insulation, and visible cracking in critical areas. Take particular note of internal and external areas in way of internal stiffener rings.

While conducting the visual exam check for damaged insulation. Make note of areas in way of the saddles or tanks where insulation is being removed for repairs, etc. This is an ideal opportunity to visually examine areas which might otherwise remain inaccessible. Also take into account the effects (corrosion, pitting, etc.) cargo, cargo vapors, and cargo contamination may have on the cargo tank.

(b) In order to avoid the need for insulation removal, different NDT methods must be chosen to check for surface cracking on the exterior side of insulated tanks. The preferred method for detection of exterior surface cracking from the interior side of the tank is SWUT combined with SBUT.

It is not the intent to use SWUT/SBUT to look for weldment discontinuities resulting from initial construction which have not caused any problems for thirty years or more. The main concern is to look for surface cracking in critical areas which extends, or could extend, into the parent metal.

Only areas which are most likely to experience exterior cracking, such as fittings and saddlehorns, will need to be tested with SWUT/SBUT. This is reflected in TABLE I. SWUT/SBUT methods will give a three dimensional picture of exterior surface cracking, and other defects, as small as 1/64 to 1/32 of an inch. WFMPT remains the preferred method for detecting interior surface cracks which may occur in the same area as exterior surface cracks. For example, according to TABLE I, 50% of the saddlehorn areas should be inspected using WFMPT and SWUT/SBUT. This means 50% of the saddlehorns should be tested using WFMPT on the interior surface <u>and</u> using SWUT/SBUT looking at the exterior surface from the interior. This is twice the amount of NDT required for uninsulated tanks because uninsulated tanks allow a 100% visual exam on the interior and exterior and insulated tanks do not. Owner/operators have the option of removing insulation and conducting WFMPT, or another acceptable testing method, on the exterior as required for uninsulated tanks. The guidelines in 3.f.(1)(b) for using WFMPT to detect surface cracks apply.

Appropriate surface preparation, as recommended in ASNT, ASME, and other industry guidelines, should be done before using any NDT method.

(c) More extensive thickness determination is considered necessary for insulated tanks than for uninsulated tanks, which are only spot checked with SBUT, because the exterior cannot be seen. The owner/operator has the option of removing insulation for visual examination or conducting extensive thickness testing. SBUT of insulated tanks for thickness determination will be done from the interior. Only six to ten circumferential belts (20 - 25' apart) will be necessary unless there is evidence of damage, corrosion or pitting, or if there is any reason to suspect the shell has worn thin. Locations of concern are: in the lower one half of the tank, where moisture could be trapped in the insulation; and at the top, near the fittings, where insulation leaks could occur. Spot SBUT should be used in way of damage and isolated areas of corrosion or pitting.

If insulation is removed for a visual examination, only spot checking with SBUT is required, conducted as per 3.f.(1)(d).

(d) Same as 3.f.(1)(c).

(e) Same as 3.f.(1)(e).

g. Insulation Removal. If the owner/operator elects to remove insulation for exterior WFMPT vice SWUT/SBUT, or for a Coast Guard required visual exam vice SBUT for thickness and condition, the following guidelines apply.

(1) When insulation is removed for WFMPT NDT, the NDT guidelines for uninsulated tanks (in TABLE I) will apply. Sufficient insulation must be removed to allow good access to the area to be tested. Give 12" clearance around tank fittings; 3' by 4' around saddlehorns; and 12" clearance on either side (two feet across) of other areas.

(2) When insulation is removed for visual exam$_1$ five to ten plugs should be chosen on each side (PORT and STBD). Plugs should be removed from the lower one third to one half of the tank, and need not be bigger than four to six inches square, unless warranted by unusual conditions.

h. Submission of NDT Proposal

(1) Copies of any previous NDT reports or the location (i.e., MSO Paducah) of the previous reports should be included with the proposal.

(2) Most areas tested during NDT should be different than those tested during previous NDT, so that all locations are subjected to NDT sooner or later, in a fairly even rotation.

4. ACTION. Owners and Operators of vessels with PVCTs are encouraged to use the guidelines in this NVIC when preparing NDT proposals for submission to the OCHI to fulfill the applicable regulatory requirements.

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Chief, Office of Marine Safety, Security and Environmental Protection

TABLE I - NONDESTRUCTIVE TESTING TO BE CONDUCTED ON PVCTS 30 OR OLDER AT 10 YEAR INTERVAL INTERNAL EXAMS

Critical Areas	Recommended % NDT	Recommended NDT Method for Uninsulated PVCTs	Recommended NDT Method for Insulated PVCTs
Fitting welds and surrounding areas	cargo sumps, pump drive and transfer line penetrations, and any openings larger than 5" diameter; and at least 50% of the remaining number of fittings	WFMPT[#] one-half of required amount on interior and one half on exterior	WFMPT (all of required amount) and SWUT/SBUT[a] (all of required amount), both on the interior
Saddlehorn Areas (See Figure 6)	50%	WFMPT one-half of required amount on interior and one half on exterior	WFMPT (all of required amount) and SWUT/SBUT (all of required amount), both on the interior
Circumferential Head welds	25%	WFMPT one-half of required amount on interior and one half on exterior	WFMPT all of required amount on the interior only
Circumferential and longitudinal weld intersections	25%	WFMPT one-half of required amount on interior and one half on exterior	WFMPT all of required amount on the interior only
Dollar plate (See Figure 7)	area around all joints, but at least 50% of the linear weld length	WFMPT one-half of required amount on interior and one half on exterior	WFMPT all of required amount on the interior only
Stiffener ring welds	5%*	WFMPT 5% of each circle of welds on both sides of each stiffener ring	WFMPT 5% of each circle of welds on both sides of each stiffener ring

NOTE: SBUT FOR THICKNESS DETERMINATION MUST BE DONE ON ALL PVCTs. SEE GUIDANCE IN TEXT OF NVIC.

* See comments in paragraph 3.d.(6)
\# Wet Fluorescent Magnetic Particle Testing
a Shear Wave Ultrasonic Testing/Straight Beam Ultrasonic Testing

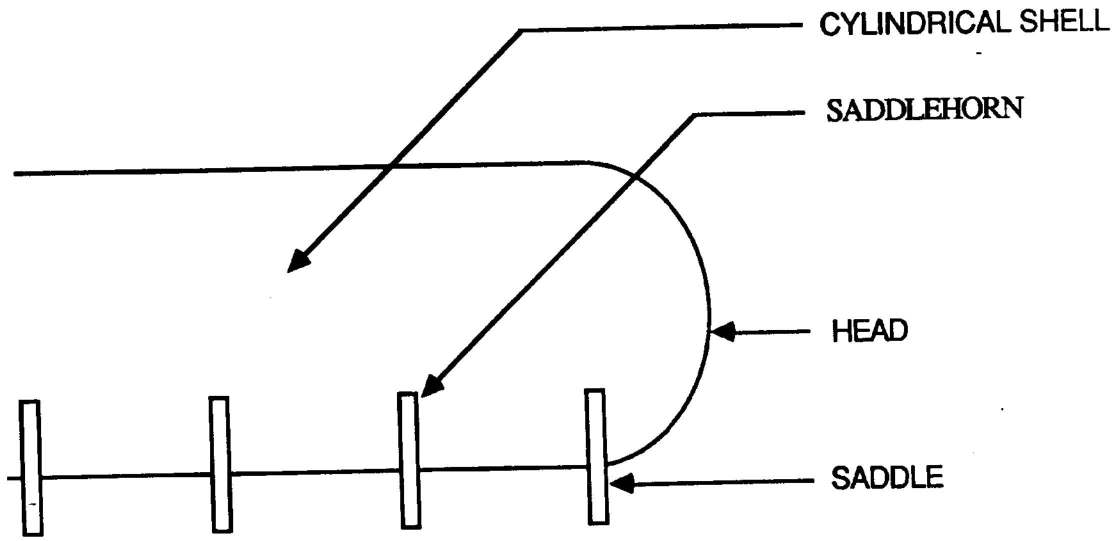

FIGURE 1 - SIDE VIEW OF TYPICAL PVCT

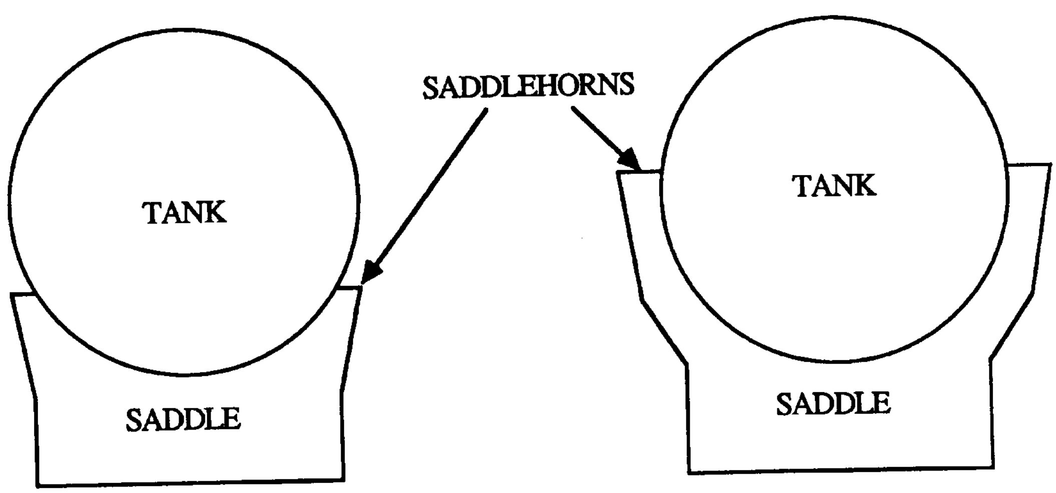

FIGURE 2A - END VIEW OF 120 DEGREE SADDLE

FIGURE 2B - END VIEW OF 180 DEGREE SADDLE

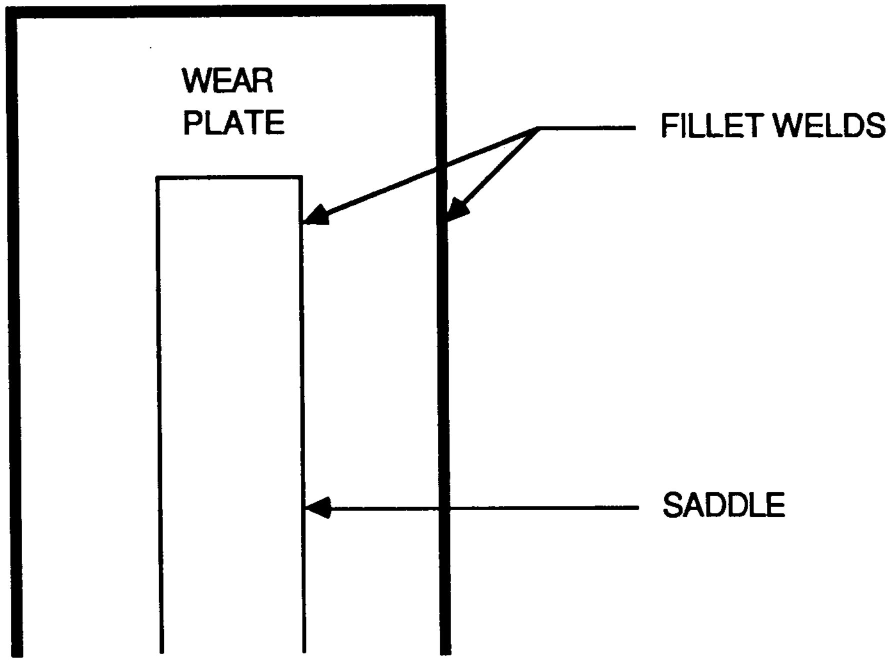

FIGURE 3A - TYPICAL WEAR PLATE CONSTRUCTION

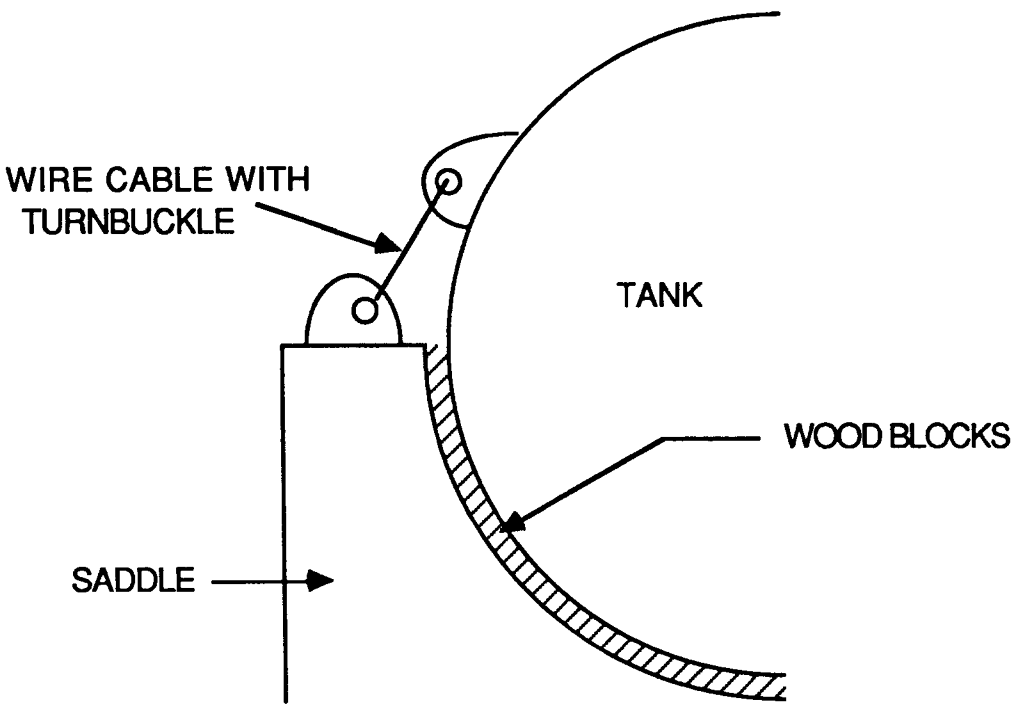

FIGURE 3B - WOOD MOUNTING BLOCK INSTALLATION. ALSO SHOWS TYPICAL METHOD OF HOLDING TANK IN SADDLE (END VIEW)

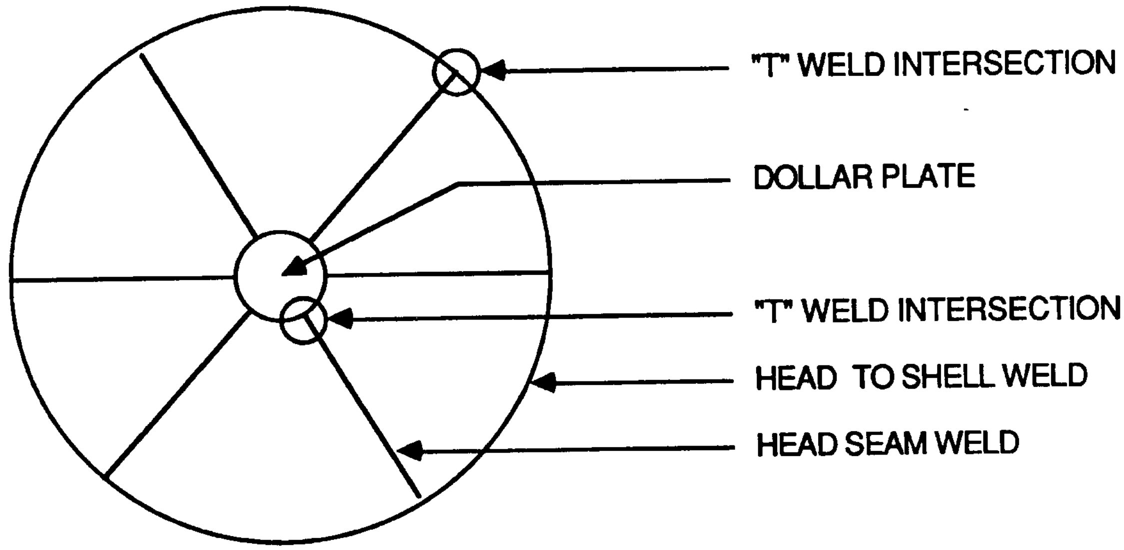

FIGURE 4 - END VIEW OF PVCT SHOWING HEAD SECTIONS

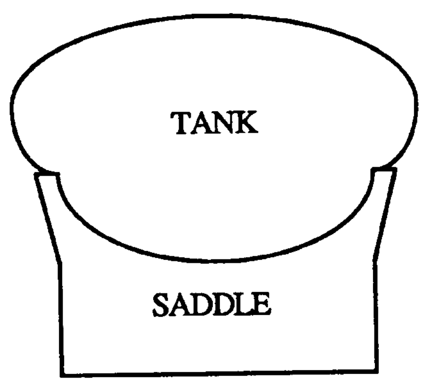

FIGURE 5 - EXAGGERATED BALLOONING EFFECT OF PRESSURIZED PVCT

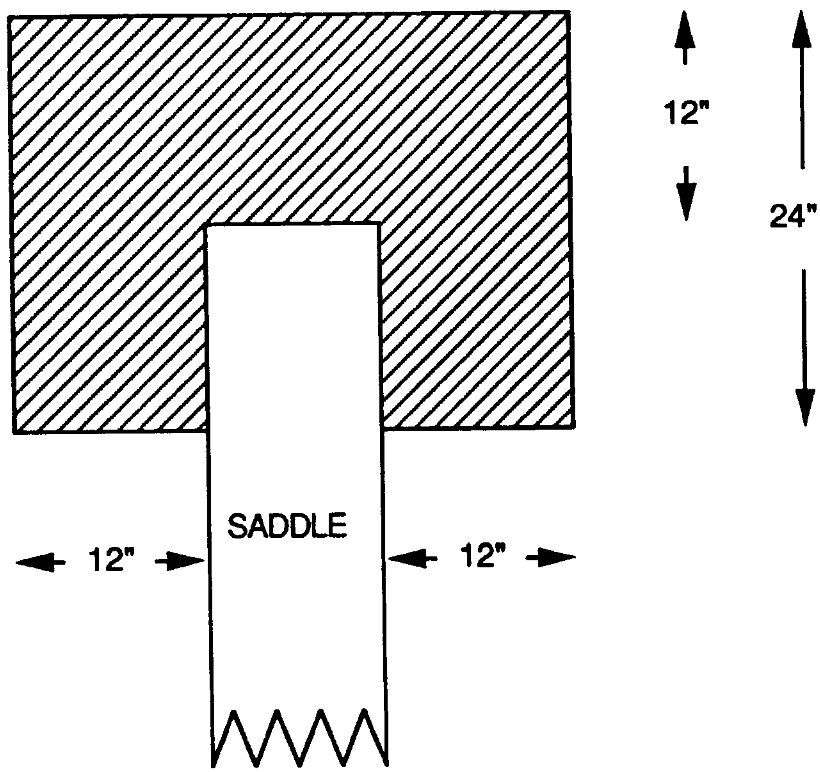

FIGURE 6 - SADDLEHORN AREA (WEAR PLATE NOT SHOWN).
STRIPED AREA TO BE NDTed.

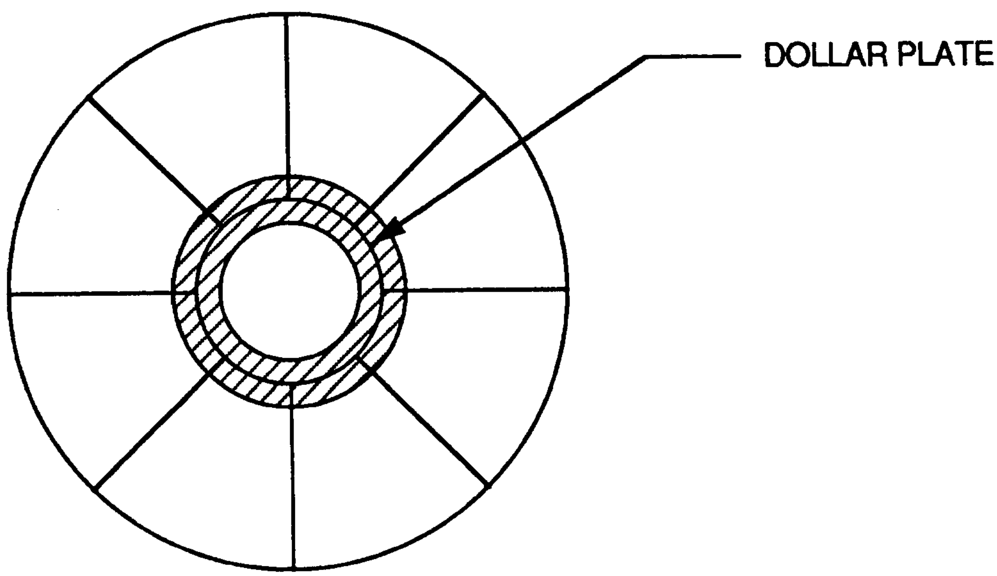

FIGURE 7 - END VIEW OF DOLLAR PLATE.
STRIPED AREA TO BE NDTed.

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