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# THE ROLE OF DESIGN IN CORROSION PREVENTION

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## INTRODUCTION

During the design of various systems, buildings and equipment, action should be taken to avoid corrosion problems in subsequent periods of operation by proper specification of materials and the use of anti-corrosion design principles. The former is a common consideration in most design efforts; the latter is equally important but frequently receives little attention. Anti-corrosion design optimizes the use of layouts, orientation and configuration to reduce corrosion attack. Its role can be appreciated when one realizes that even the best specified systems, buildings and equipment can suffer serious corrosion damage or have unnecessarily high maintenance costs unless correct design procedures are used to avoid corrosion. What follows is a design philosophy wherein the application of common anti-corrosion measures and techniques will reduce corrosion losses.

## DISCUSSION

Faulty design is often a major factor leading to corrosion. An understanding of the role that design plays in corrosion prevention will help ensure that the facilities, structures, and equipment designed will fulfull their intended purposes. The desired systems will last as long as necessary and also retain good appearance in those situations where esthetics are a major concern. The use of anti-corrosion design principles also provides balanced economics that will produce a minimum cost when capital and operating expenditures are both considered. Another significant consideration in the examination of system economics is the knowledge that appropriate remedial action during the design stage has a minimum overall expense; changes to the system or equipment at a later date can result in prohibitive costs.

The acceptance and use of design measures and techniques to avoid corrosion has been somewhat restricted. A major function in their slow acceptance and use has been a lack of understanding of their elementary principles by designers and architects. The primary thrust in combating corrosion has been through the specification of resistant materials. Another factor contributing to their limited use is what appears to be an occasional conflict between designer goals and those that are of greatest operator benefit.

Because the effects of design have been recognized for many years, generalized rules have been evolved that should govern the design of systems, structures, and equipment; these will be presented. Subsequent discussion will be centered on examples of good and bad design practice, remedies for those unfortunate cases of bad design and different system needs.

No attempt will be made to enter into a detailed analysis of mechanisms. It is assumed that all are acquainted, at least in general terms, with the basic forms of corrosion such as crevice corrosion, galvanic attack, etc. Both detailed and summary information on the types of corrosion can be found elsewhere.(1-4)

## Anti-Corrosion Design Rules

Over the years, experience has led to the formation of generalized rules to govern the design of systems and equipment in such a manner that corrosion is reduced. Table I lists these recommendations as noted or stressed by Fontana and Greene, Colburn, Hopkins and Burton.(3-6)

Table I

Anti-Corrosion Design Recommendations

1. When locating facilities, choose the least corrosive environment.
2. Avoid crevices.
3. Join by welding rather than riveting.
4. Design for easy draining and cleaning.
5. Design for easy component replacement when rapid failure in service is expected.
6. Avoid excessive mechanical stresses and stress concentrations.
7. Avoid contacts between dissimilar metals.
8. Avoid sharp bends in piping systems.
9. Avoid heat transfer hot spots.
10. Exclude air from systems.
11. Avoid heterogeneity in systems.

There are exceptions to these recommendations; for example, titanium and stainless steels are more resistant to acids containing dissolved oxygen or other oxidizers. Such conflicts will be treated in greater detail in the section on different system needs.

## Good and Bad Design Practice

Discussion of examples of good and bad design practice is subdivided to follow the classical elements of design such as site selection, location, layout, structurals, joining vessels, piping, and floors. For presentation, an arbitrary distinction has been made between site selection and location. The former will deal with anticorrosion design considerations involved in placing facilities within broad geographic areas. The latter will focus on those aspects of design to avoid corrosion in narrowly defined areas or even one specific piece of real estate. Graphic display is given to examples of those problems most frequently encountered in industry and which are, consequently, of broadest general interest. Particulars follow:

o Site Selection. The location of facilities and plants is an important consideration in corrosion prevention because of the variation in the corrosivity of various environments. For siting purposes these different environments may be considered as falling into three general classifications, industrial, rural and marine. The effects in all are primarily governed by moisture levels and oxygen, but are accentuated by contaminants such as salt and air pollutants.

The role of proper site selection in reducing corrosion can be better understood when comparative corrosion losses are considered. The corrosion of steel in the atmosphere, for example, can be 400 to 500 times as great on the seacoast as in the desert.(3) Atmospheric differences are further accentuated by topographical, meteorological, air quality and use differences. Once recognized these factors can be used to reduce maintenance and operating problems from corrosion by judiciously placing plants where these have the least economic impact.

To realize the best economic balance in site selection, the designer and corrosion specialist must work with corporate planners. The latter use economic balances between transportations, marketing, raw material and operating costs to locate facilities and plants within broad geographic areas. The relative costs from corrosion and material losses at various candidate sites may well affect estimated operating costs sufficiently to influence site selection. To date there has been little corrosion control input into these considerations.

The effects of climate and geography on corrosion have long been recognized. Some organizations, such as the American Society for Testing and Materials (ASTM), have conducted programs over many years to determine and catalog the relative corrosion effects of different sites throughout the world.(7) Recently Rychterna and Němcová(8) developed a world classification map to show the relative corrosion and degradation effects for various geographic regions. United States Weather Bureau fog maps, general rainfall information and seasonal precipitation data are also useful in making qualitative estimates of the relative corrosion behavior assessments. For example, the work of Thomas and Alderson(9) showed that higher corrosion losses were experienced than might have been expected from annual rainfall and temperature data in Northern California. Use of fog maps and seasonal precipitation data as shown in Figures 1 and 2 would have helped to anticipate that losses would be higher than those experienced in New England and North Carolina where there are higher annual precipitation rates. In the latter two locations rainfall was sufficient in the summer to wash off most of the deposited salt from steel surfaces. In California moisture from fog and dew accelerated the corrosion attack.

The information reported by Yocom(10,11) on the effects of air pollution on corrosion and material degradation can be used by the designer and corrosion specialists. These adverse effects are caused by $SO_2$, $CO_2$, ozone, $H_2S$ and moisture. In the late forties the U. S. economic loss from air pollution degradation effects was estimated to be 1-1/2 billion dollars. In England, material losses in heavily industrialized areas were twice those encountered (as an average) elsewhere in that country.(11) This was attributed to air pollution.

Because industrial concentration and topographical and meteorological conditions differ, the air pollution effect varies throughout the world. Information is available, however, to help site plants to avoid these problems if corrosion losses become a critical consideration in operating costs. Charts are available that give high pollution potential day forecasts for the U. S.(12) These show where high levels of air pollution can be expected over wide geographic regions because of stagnant high pressure centers. Such pressure centers tend to become stationary over California and the

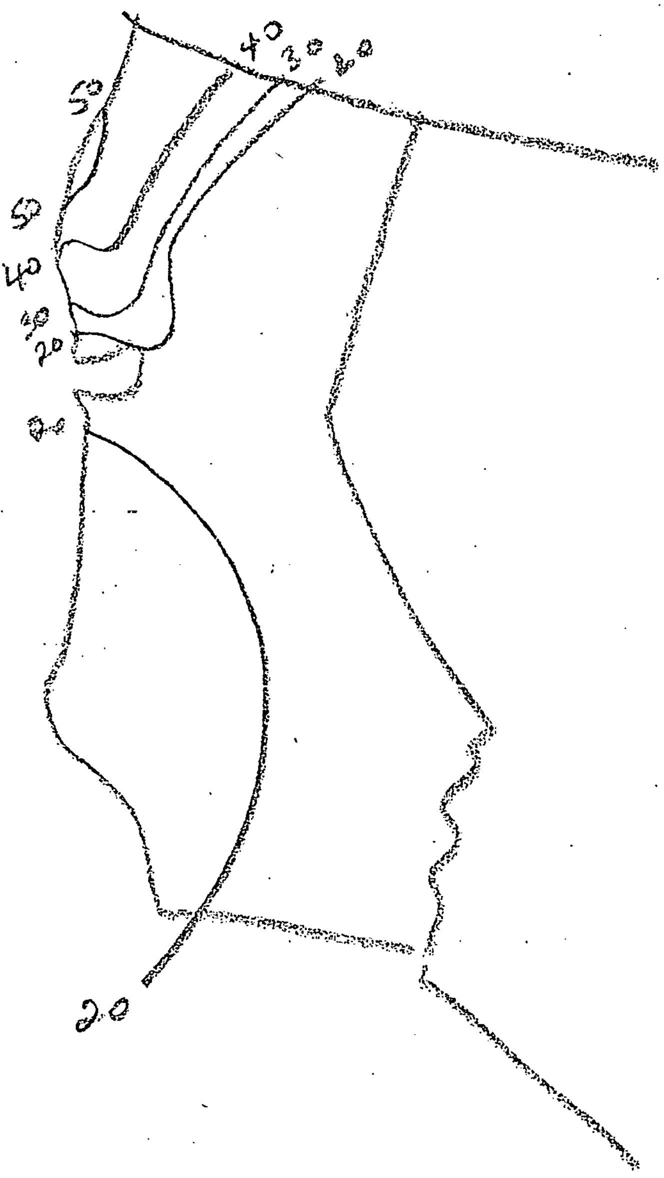

Figure 1. Average Annual Number of Days of Dense Fog in California

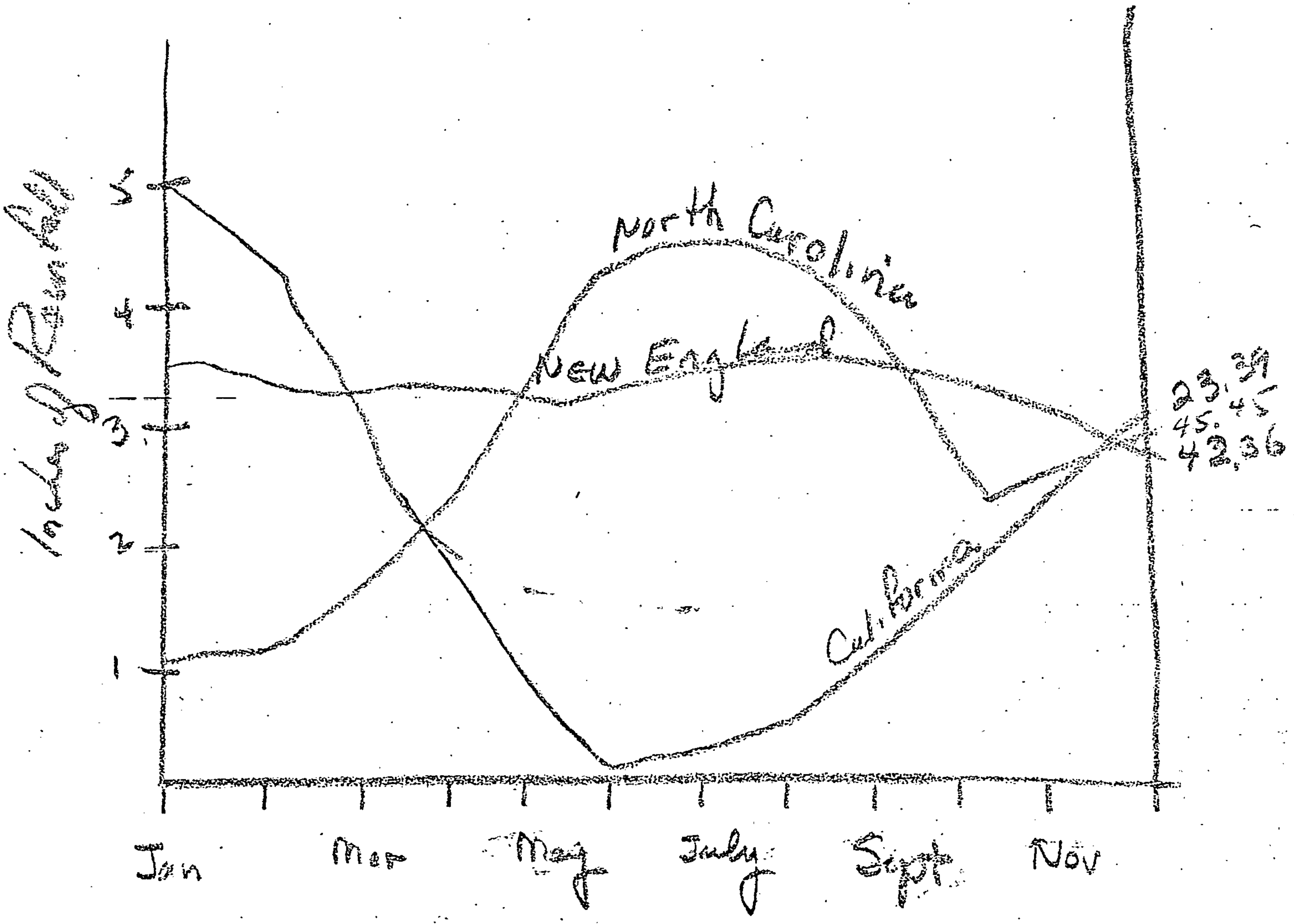

Figure 2. Average Precipitation Data

Appalachians. They can become unusually bothersome in the Los Angeles area, for example, where topographical features prevent the movement of air to the east and dispersion of air pollutants.

In the continental United States, there are many of these types of aids available to help estimate the relative corrosivity of various geographic areas. These assessments should be made and input supplied in the decision making process on plant site selection so that corrosion losses can be reduced to a minimum.

o <u>Location.</u> Anti-corrosion design considerations relating to the location of equipment and facilities are similar to those found controlling corrosion in siting determinations. The geographic area of concern is limited, however, to specific locality variables or even to those encountered on a particular piece of property. In addition to the atmospheric variations that were discussed in the previous section, there are variations in soils that are of great importance. The corrosivity of the latter are related to pH, moisture, permeability to air and water, biological activity, composition and stray currents.

Distance from the sea is an important variable in reducing corrosion of equipment and facilities in coastal areas. Data from the atmospheric test facilities at Kure Beach, North Carolina, show that corrosion losses, in steel for example, are much higher 80 feet from the sea than they are at 800 feet from the sea. Systems should, then, be placed as far from the sea as is feasible. The role of prevailing wind can be shown with Figure 3. The structure near the windward beach will suffer greater corrosion than the downwind facility, which is equally as close to the shore but on the leeward side of the peninsula.(4)

The importance of location in soils with a low corrosion potential can be illustrated by the two situations shown in Figure 4. A slight relocation of the pipeline to the preferred position would avoid a particularly bad area and at little or no extra cost. Parker (13) cites information on an actual case where the use of strict line-of-sight placement would have run the pipeline through several slush pits and one salt-water pit similar to those shown in Figure 4. In addition to the obvious advantages accruing to installation of the pipeline in the more desirable location, there is a much lower probability of future corrosion problems.

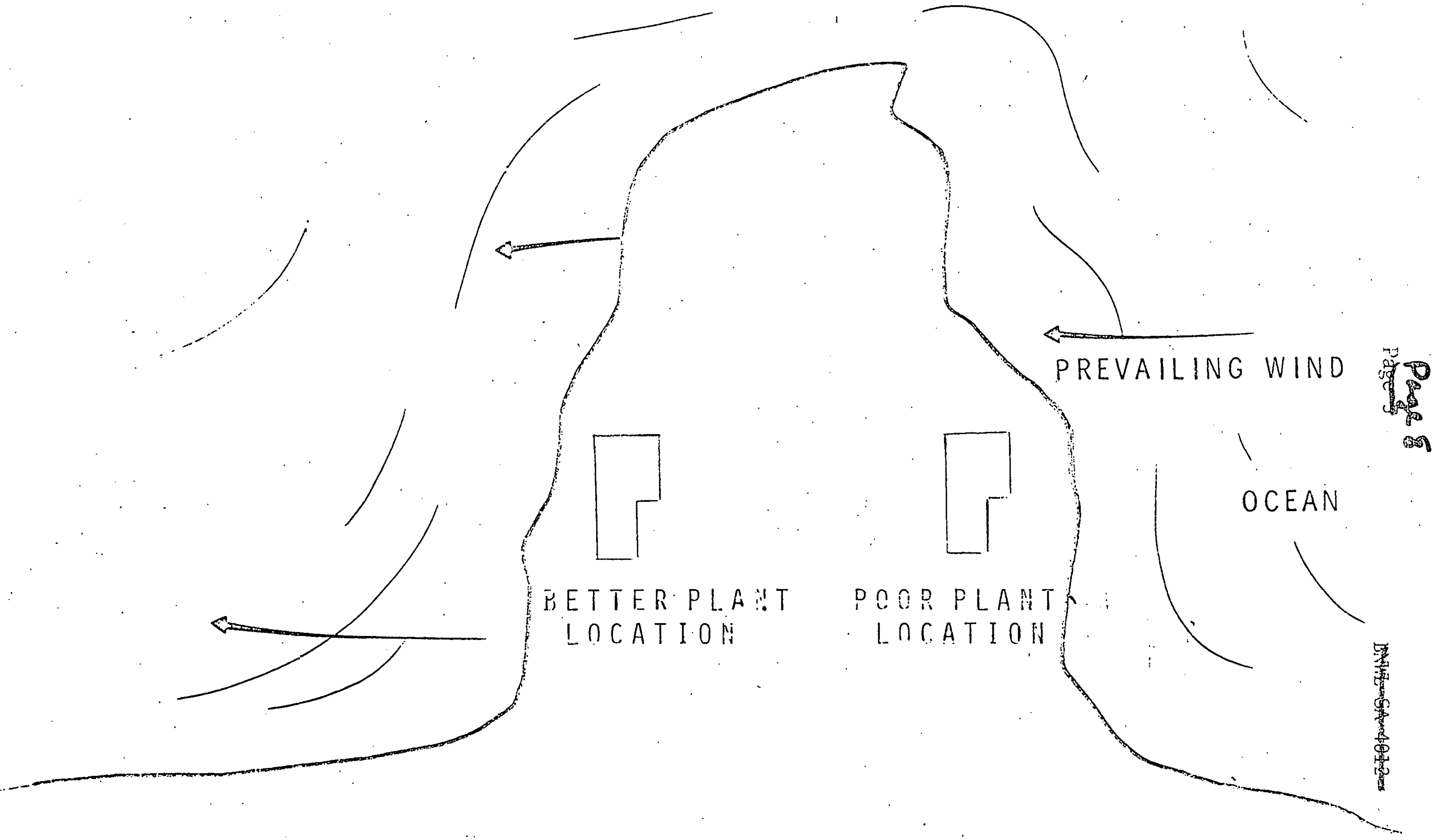

Figure 3 Effects of Prevailing Wind on Siting

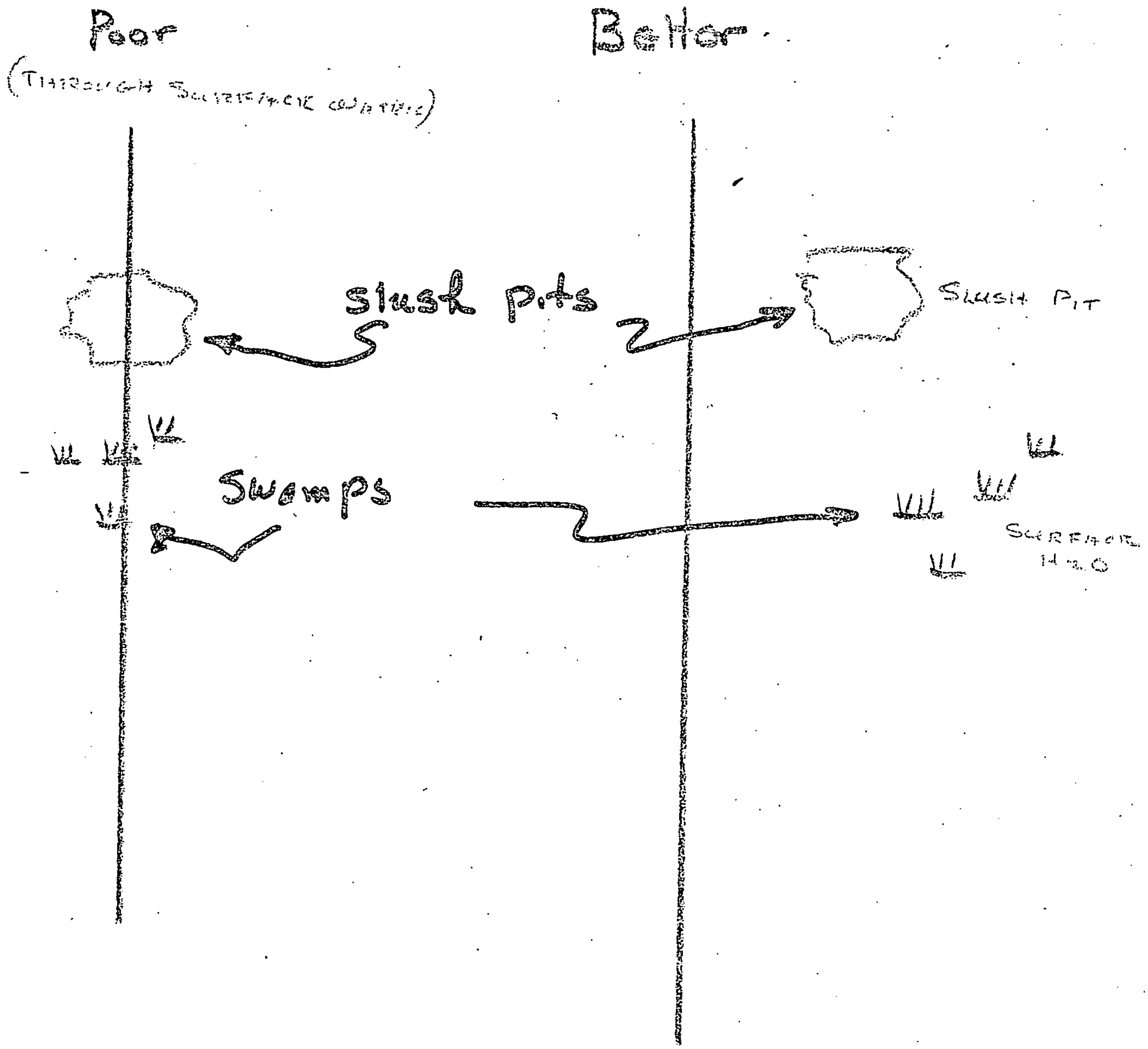

Figure 4. Effects of Buried Pipe Line Location

The movement of airborne effluents is very complex and governed by the interaction of terrain, meteorological conditions and design of the effluent discharge source. Published information on the disperal of these effluents (11,12) can be used to advantage by the designer in locating facilities so that exposure to adverse conditions will be kept to a minimum. Of great importance in combating the potential corrosion effects of air pollution is knowledge of wind direction persistence. These data are commonly compiled to show the frequency at which wind blows in a given direction for a specified number of hours. The persistence data given in Table II are used in Figure 5 to show the most desirable and least desirable locations for placing a facility in the close proximity to a single stack source of air pollution. When several buildings are to be constructed in a complex, the building that produces the corrosive fumes should be located downwind from the other buildings.(4)

Table II*

PERSISTENCE OF WIND DIRECTION

| | N | NE | E | SE | S | SW | W | NW |
|---|---|---|---|---|---|---|---|---|
| 6-12 hrs | 24 | 26 | 5 | 47 | 54 | 78 | 79 | 38 |
| 13-24 | 1 | 5 | 0 | 16 | 16 | 24 | 28 | 11 |
| 25-36 | 0 | 2 | 0 | 0 | 3 | 0 | 6 | 1 |
| 37-42+ | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 |

Note: The data indicates the number of separate instances in a single year during which the wind remained within the 45 deg sector indicated.

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*Taken from Reference 12.

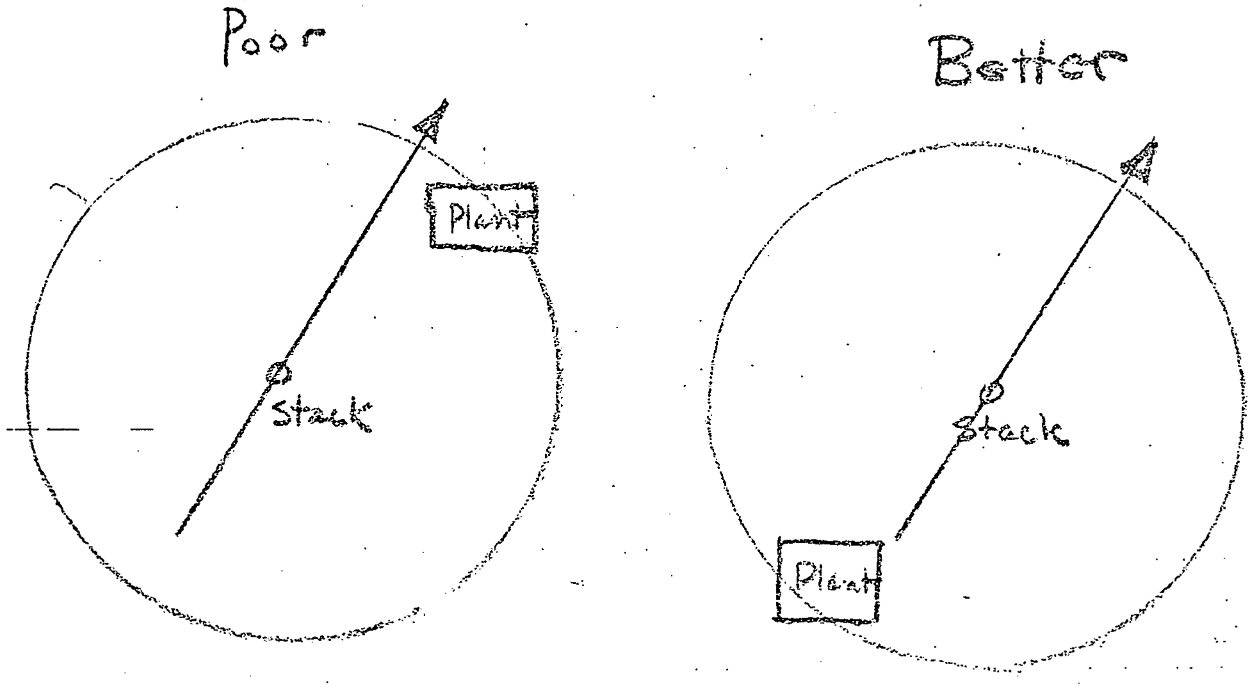

Figure 5. Effects of Wind Persistence on Plant Location

The deep river valley location shown in Figure 6 is an idealization of the air pollution problem encountered at Trail, British Columbia. Frequent meteorological inversions tend to hold the gaseous effluent close to the valley floor.(4) The possibilities for corrosion of facilities and equipment in this environment are much greater than those that would be encountered where the stack effluents were not so well contained. The designer should pay particular attention to the problems of effluent being essentially trapped or diverted by terrain, and place his facilities elsewhere to avoid the higher maintenance and operating costs that would be found under the conditions similar to those shown in Figure 6.

The possibility for corrosion attack is greater in sheltered areas where the relative humidity may be high and the sun and wind do not have the chance to remove condensed moisture from the metal.(3,4) This can be avoided by placing buildings so that circulation is enhanced.

The designer frequently has considerable latitude in selecting a specific location within a comparatively narrow geographic region. With this flexibility and a knowledge of the effects of climate, terrain and corrosive atmospheres on materials, he can play an important role in reducing maintenance and operating costs.

o Layout. The prime consideration in the layout of facilities and equipment is to provide for the most economic relative location of the various items involved in the process. Frequently these determinations have been made without input from personnel concerned with corrosion and its subsequent influence on maintenance and operating costs. To reduce corrosion by proper layout, the designer becomes concerned with accessibility, relative orientation, and relative position of the various items in the process.

The importance of relative position effects in the layout of systems is shown in Figure 7. If both stacks discharge essentially the same effluents they should be of the same height even though one may carry a much more larger volume of effluent material. The discharge of fumes from one stack against the side of another can lead to severe corrosion.(15) Even in the desired position, plume problems can be encountered under certain meteorological conditions

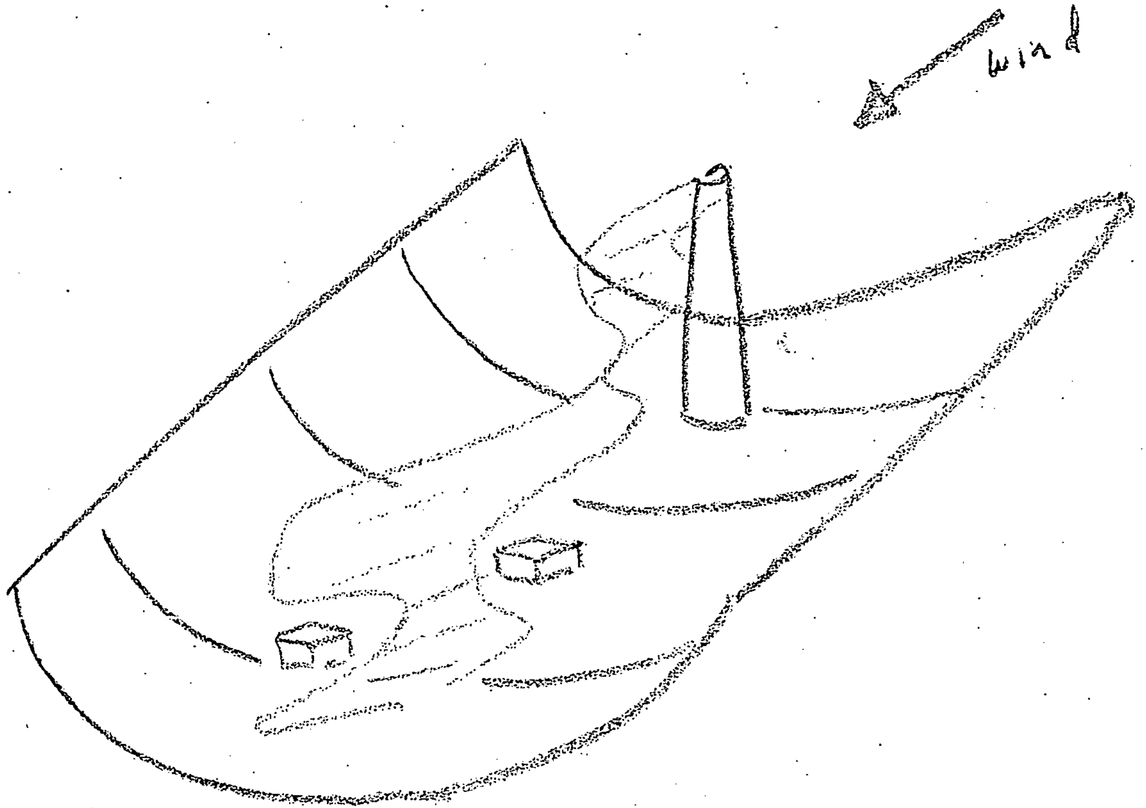

Figure 6, Effect of Inversions on Flow of Stack Effluent in Deep Valleys

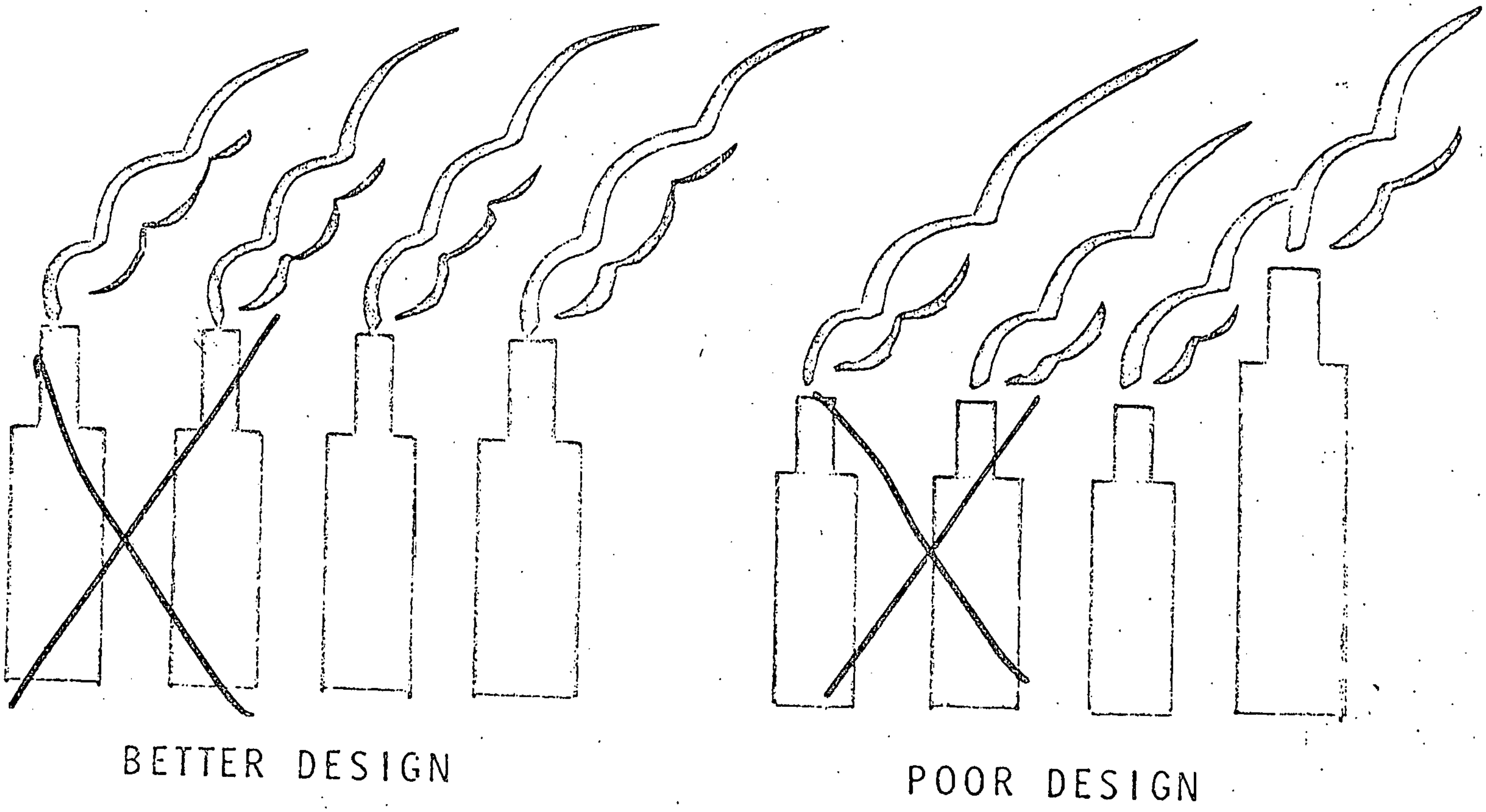

Figure 7. Effect of Stack Height

for two closely situated stacks that have "downwash" or "creep" of the effluent down the stack. However, for well-designed stacks, the exposure to these undesirable conditions will be minimal, and equal stack heights will reduce the overall amount of attack.

The need for proper access manifests in several different ways. Cleanliness, for example, is an important variable in reducing corrosion. Operators and maintenance personnel must be able to reach equipment to remove spillage, grime, etc. Further to the point, operators and service personnel will only clean a system or plant routinely if it is easy to clean.(5) The designer has the added charge of making it easy - not just feasible or possible to clean - for corrosion prevention benefits to accrue.

Koger and Roebuck have described systems that have been constructed with specifications calling for the application of protective coatings.(16,17) In one case it was the supporting structure for a shipboard and helicopter landing pad, and in the other, a large container. The supporting structure consisted of a maze of interlacing structural steel, and the latter had a single, very small opening. In neither case could specifications be met; it was impossible to apply the coating because the designer had not provided access for personnel and their equipment to completely prepare the surfaces and apply the protective coatings.

Many segments of industry are now using modern operations management techniques in the layout of process and product oriented production systems. Depending on the complexity of the layout problem, either graphic or computerized procedures are used to provide the most economical relative layout of the process. These have been described by Buffa(18) and are ammendable to anticorrosion design inputs. Relative corrosion costs for different candidate layouts must be estimated and fed into the calculational process so that the best overall economic balance may be obtained. Relative cost input should be provided in the logic step concerned with total handling costs. Those interested in anticorrosion design would be remiss by not recognizing the use of advanced techniques such as this and applying appropriate costs so that proper restraints are computed into the layout models to provide for reduced corrosion.

- Structurals. Tees, channels, angles, "I" beams, square beams, rectangular beams and tubular beams are used to carry structural loads and give shape to facilities and plant systems. Because of configuration, certain of these structurals are more susceptable to corrosion than others. Figure 8 shows the more desirable shapes from an anticorrosion standpoint. The most desirable are those that will not catch and hold solutions and dirt. Where those structurals such as tees, angles, channels, etc. are used that can retain solutions or dirt, care should be used to orient them so that retaining edges are pointed down as in Figure 8.

  As another consideration for the designer, box, rectangular and tubular beams cost less for equivalent strength capacity and also to sand blast and paint. They also have the fewest surfaces and the smallest number of possibilities for "edge effect" coating flow. The tubular beam is of course ideal; there are no edges.

- Joining. The common joining procedures are welding, bolting, riveting, and use of screwed connections. These are a source of concern because they frequently provide crevice or stress areas that establish anodic-cathodic cells. Another major corrosion problem arises from joining dissimilar materials that create galvanic cells. Landrum has identified crevice corrosion effects as the most prevalent cause of equipment failure; care should be exercised to avoid this problem in joining materials.(19) These crevices become cells when they are filled with solutions that have concentrations or temperatures that are different from bulk process conditions.

  Figure 9 shows good and poor welding practice for joining support plates. Continuous welds on both sides, although more expensive, avoids the crevices created by skip welding. The latter may be a more economical fabrication technique, but maintenance costs can easily offset this initial advantage in any corrosive environment. A smooth surface on the butting edge of the upright plate shown in Figure 9 will help avoid problems. Any weld porosity with a rough plate edge, as shown in the "poor practice" case, could lead to a severe corrosion problem.

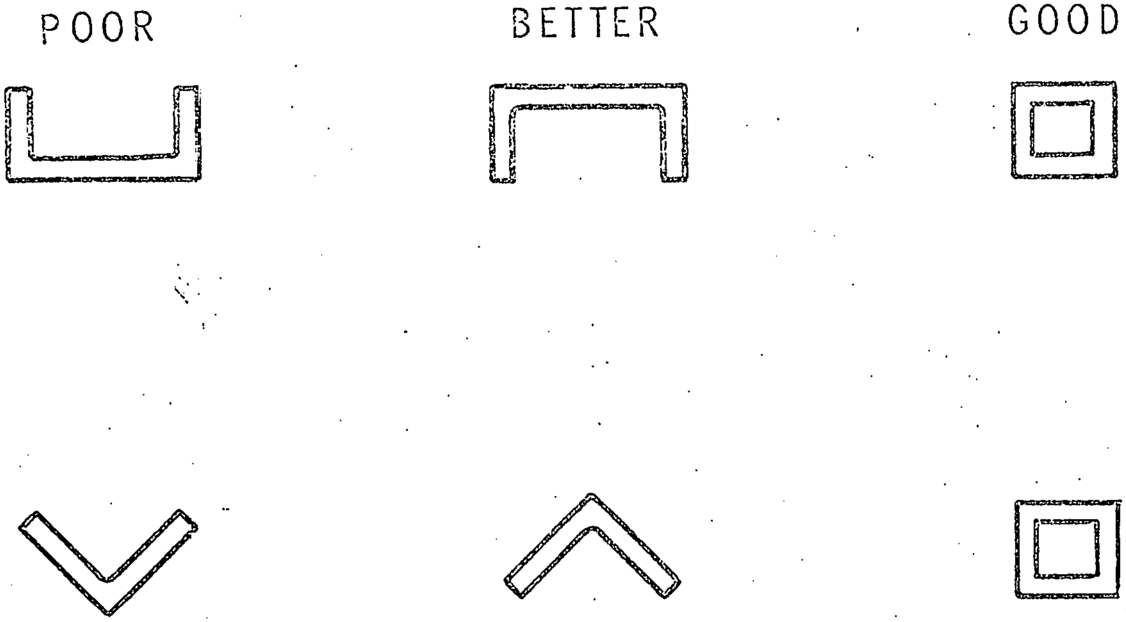

Figure 8 Structural Member Effects

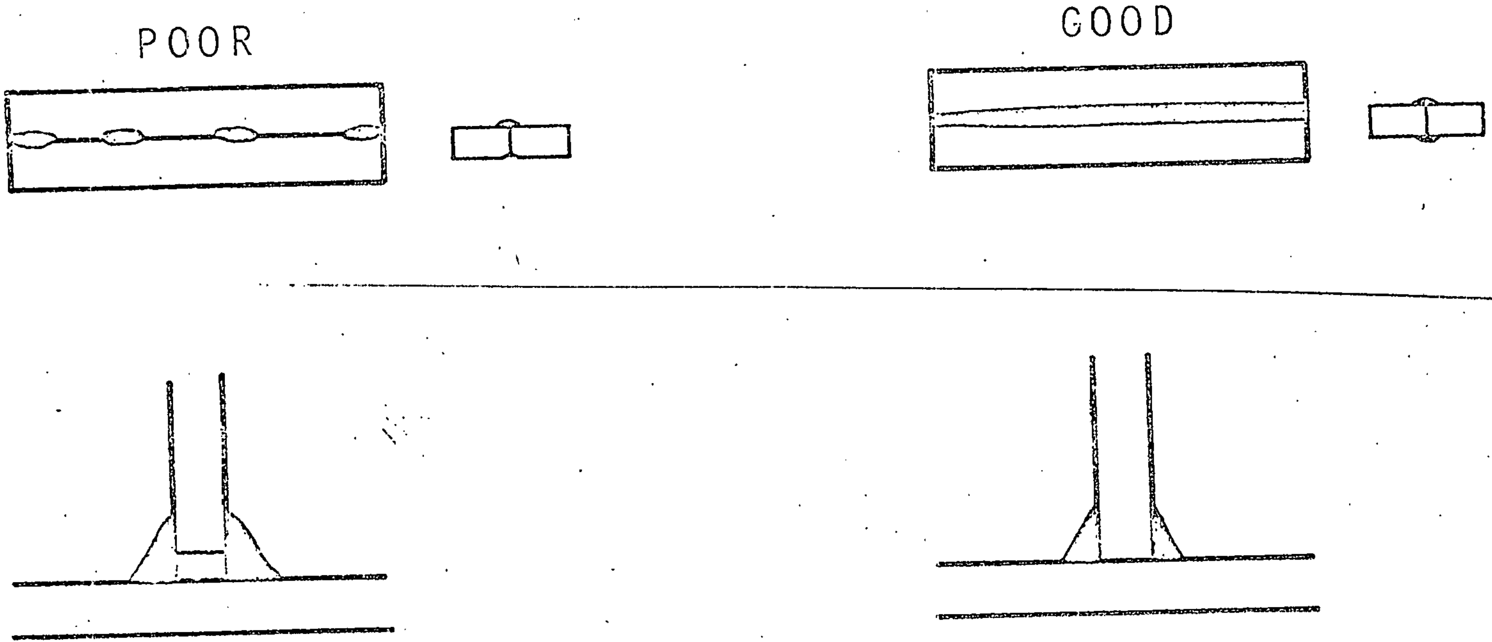

Figure 9 Joining Practices ~~for abutting upright plates~~

- Vessels. Vessels are an integral part of the process industry and transportation system. They are also frequently designed so that the possibilities of having corrosion problems are enhanced rather than avoided. In Figure 10 common techniques for removing liquids are shown. The discharge line should be located so that the vessel may be completely drained; otherwise, sludges or solutions of different concentration can accumulate. These could cause galvanic corrosion. The heel left after draining in the "poor" design cases would also lead to perferential attack problems Similar difficulties could be encountered if baffles and diverters were not located correctly and designed to allow complete drainage.

  Figure 11 shows good, fair, and poor practice procedures for use of concrete supporting pedestals. Use of a continuously welded collar supported by a metal saddle adjacent to the concrete will reduce corrosion from spillage. Use of only the welded collar adjacent to the concrete support may be acceptable if the expected service life of the tank is comparatively low or the environment is not overly aggressive. Direct contact between the metal tank and the concrete offers a potentially serious maintenance problem where there is an opportunity for spills or frequent exposures to corrosive sprays or mists. For tanks with the long axis vertical, frequently a crowned concrete pad is used to avoid problems. Additional protection can be obtained by having an additional layer of steel attached with a continuous weld to the bottom of the tank as shown in Figure 12.

- Piping. Piping is a ubiquitous part of industry. It is used to transport fluids and slurries of different corrosivities through industrial, rural and marine environments, and through different soils, all of which have different corrosion effects. The general tenets of anticorrosion design that reduce the possibility for corrosion in these cases are shown in Figure 13. Inpingement and turbulence should be avoided wherever possible. Deadlegs or stagnant flow regions are also undesirable. Instrument sensing lines, for example, should enter from the top of a pipe rather than from the bottom. The latter situation creates a deadleg that may lead to severe corrosion in aggressive solution environments. Avoidance of deadlegs becomes even more important in those systems where chemical

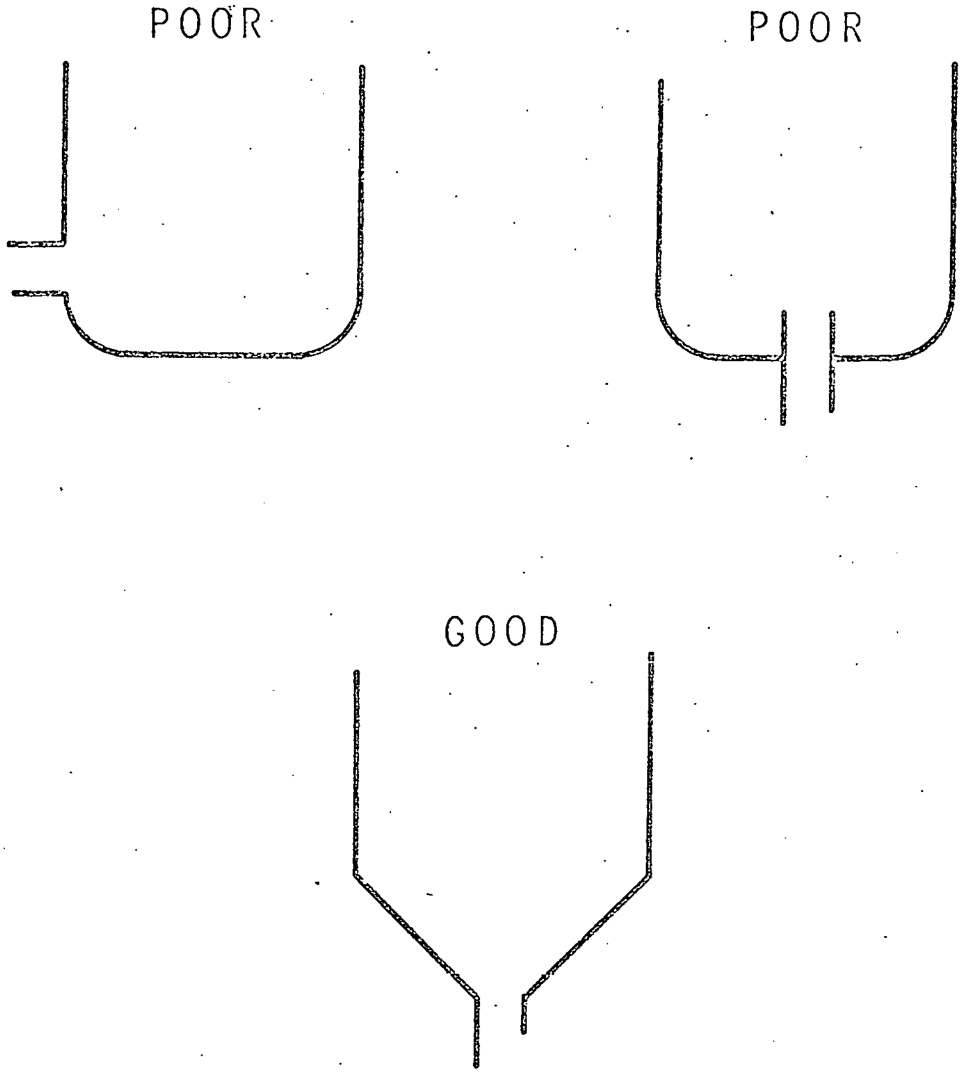

Figure 10. Tank Drainage

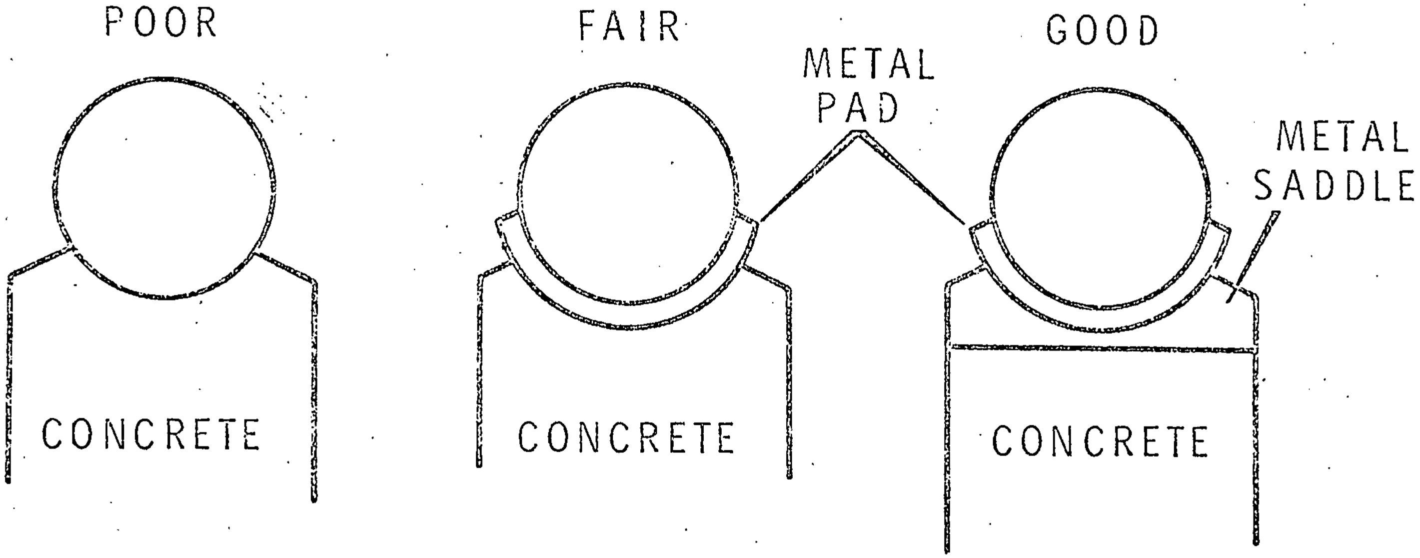

Figure 14 Concrete Tank Supports

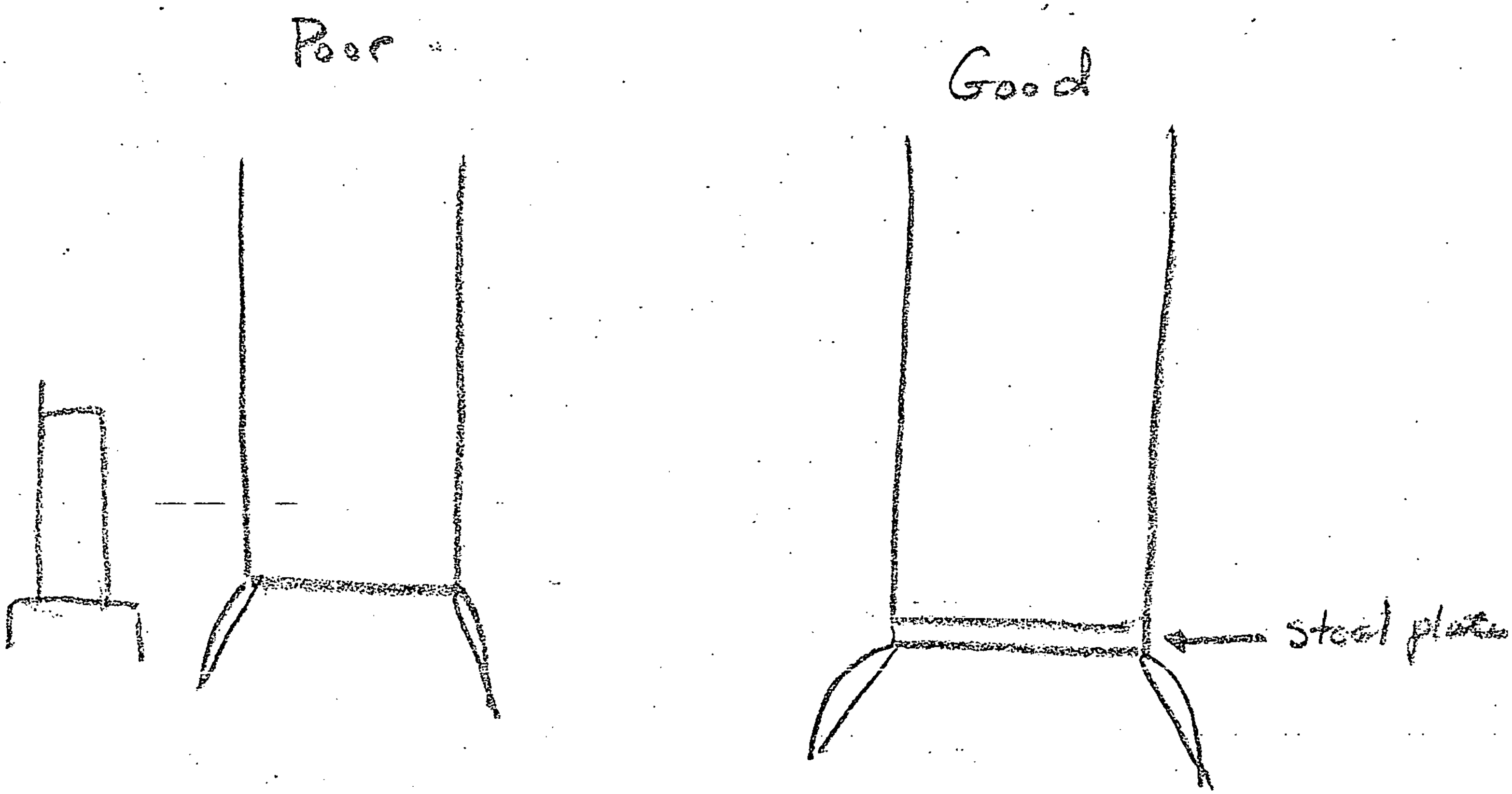

Figure 12. Tank Supports

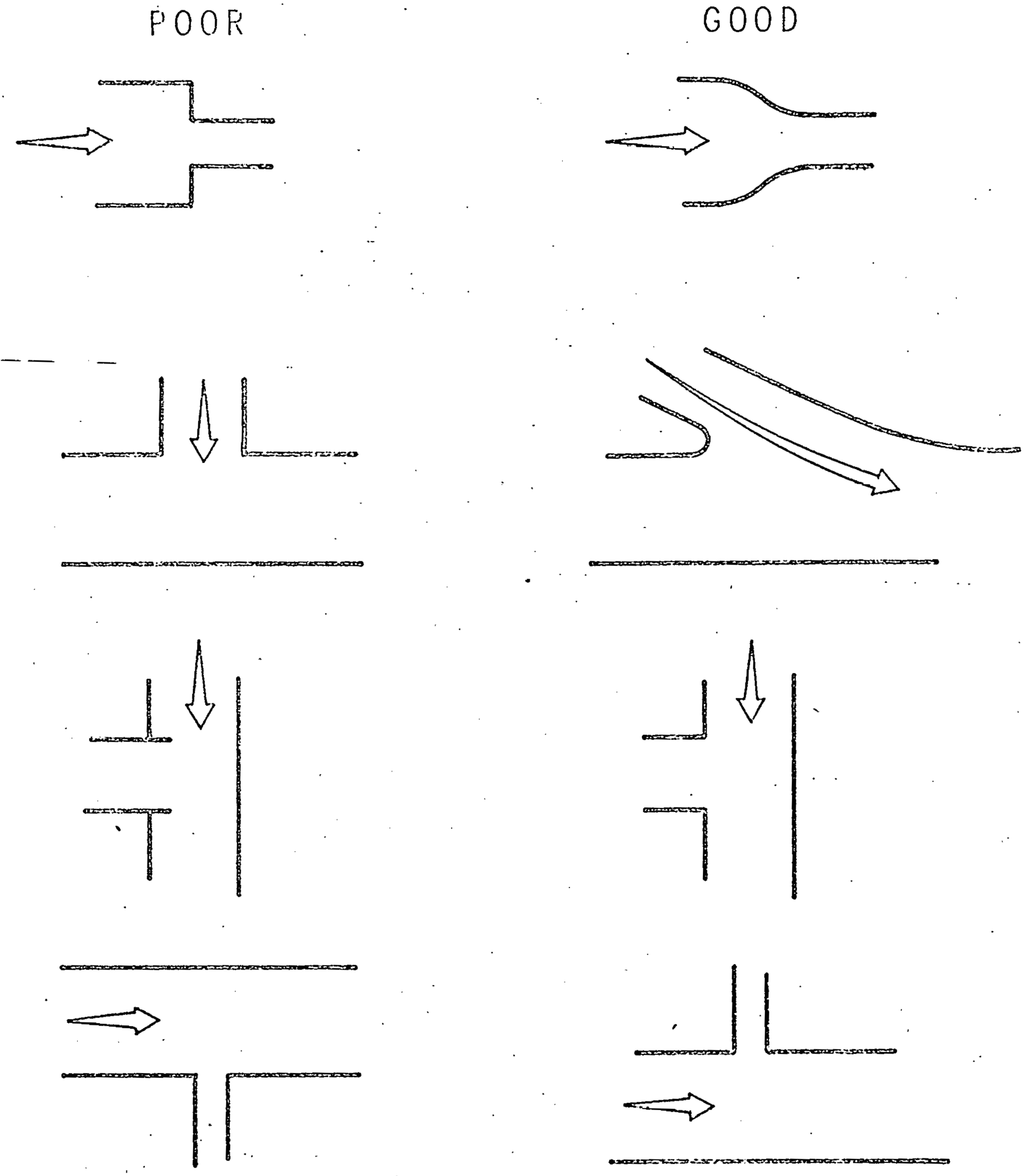

Figure [illegible] Piping Design

cleaning may be necessary. Loucks(20) and Perrigo(21) have described the problems that can be encountered if solutions cannot be readily introduced and removed. One of the most frequently encountered sources of deadlegs is the mismatching of process area lines with their continuations in yard banks.(22) This not only involves dimensional errors but leads to unnecessary twists and turns on one side of a match line to meet a point on the other side.

Vapor pockets can also lead to preferential corrosion. As shown in Figure 14 this problem may be avoided by suitable use of vent lines. Piping runs should be sloped for easy draining. Most piping corrosion problems can be minimized by proper arrangement or orientation; these factors are completely controlled by the design engineer.

Burton and Landrum have described examples of how uneven heat transfer in flues can lead to severe corrosion.(6, 19) The supporting members in Figure 15 act as cooling fins if they are not properly insulated. The localized cold spot can drop the temperature below the dew point causing condensation. Sulfur oxides in the flue gases will produce dilute sulfuric and sulfurous acids which will accentuate the condensate attack on mild steel surfaces.

o Floors. In this discussion, floors are defined as all industrial structures where people walk. This includes concrete slabs, tile, acid brick, wood, decking and grating.

Industrial floors, especially those exposed to corrosive spillages, frequently receive less design study than any other part of the building process.(23) The consequences of inattention can be serious. Production may be lost, the stability of structures compromised and hazards to attendant personnel created. Hopkins notes than an easy and inexpensive method for reducing floor attack is to slope all floors and provide sufficient floor drains.(5) Monolithic concrete has advantages in certain systems, while floors with sacrificial tile may be the most useful solution to spill damage in others. Metal decking with isolated skid-resistant protrusions is much more desirable than interlocking diamond or ring varieties.(15) The latter retain solutions, which enhances corrosion of the surfaces.

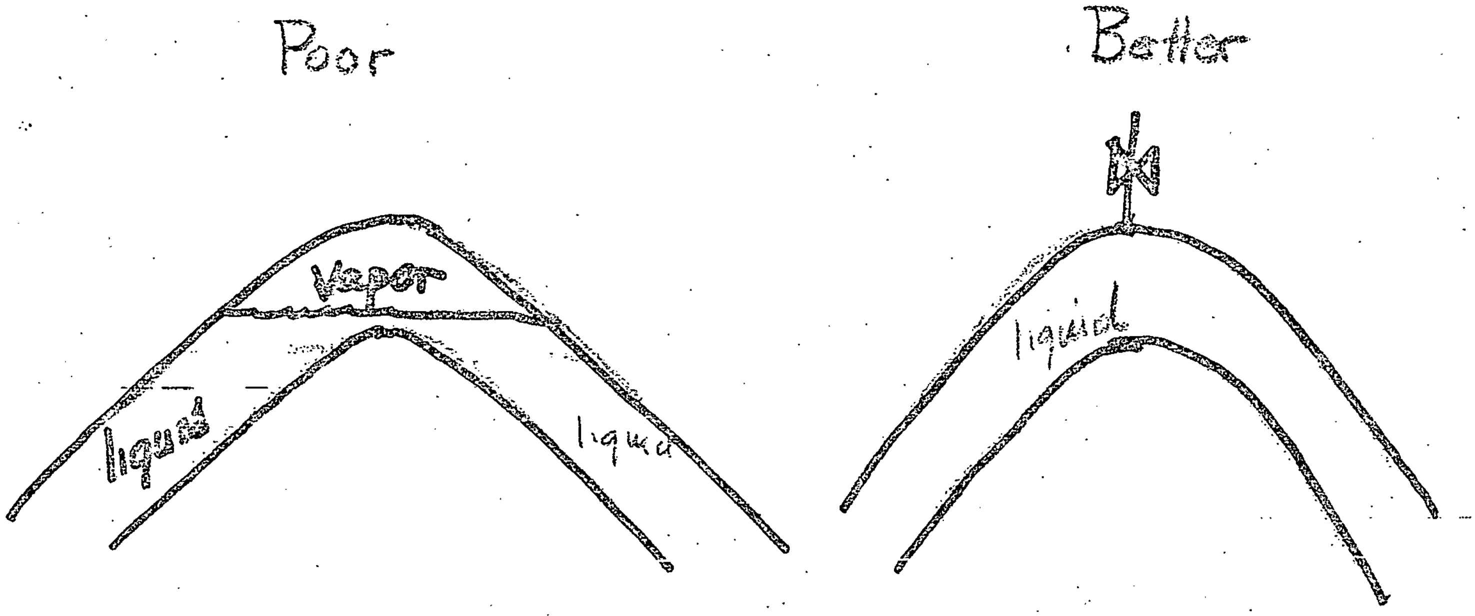

Figure 14. Vapor Pocket Effects

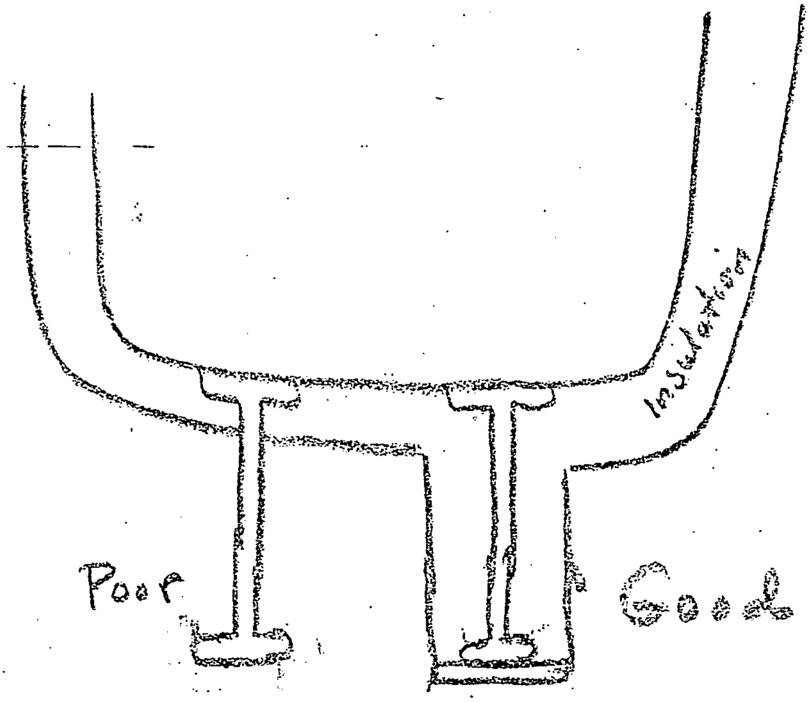

Figure 15. Avoid Corrosion with Insulation

Figure 16 shows six designs of commonly used industrial gratings. These are classified in this presentation according to their design features for avoiding or promoting the possibilities for corrosion. The welded grating variety shown in Figure 19a contains no crevices or solution holdup areas. In its desirable form the perforated plate grating has similar attributes. Care should be exercised in selection of this variety to avoid those produced by punching processes that cup the metal enough to retain solutions at various places on the surface. The ridged-mechanical joined, the interlocking key, riveted and interlocking joint varieties all have crevices and some holdup areas. They should not be used in corrosive atmospheres.

## Remedies

Because anticorrosion design has not been widely used in many industries, many poor designs have been placed in service. Frequently, there are opportunities for remedial action where some or all of the undesirable effects of these unfortunate situations can be avoided at a minor cost. Figure 17 shows how corrosion of tank support members resulting from spillages may be minimized.(19) Sheet metal may be joined by a continuous weld to the tank to act as a drip skirt. Protection may be given to structural members by drilling holes in the webbing at frequent intervals as shown in Figure 21.(19) Also, packing and protective coatings may be usefully employed to cover crevice and holdup areas. Care must be exercised to ensure that the crevices and holdup areas are thoroughly covered, however, or more serious problems could result. Many hot spot corrosion problems can be avoided by rearranging the location of the heaters with respect to vessel walls or avoiding direct flame impingement.(19) Cold spot heat transfer-induced corrosion problems may be avoided by adding insulation to tanks and piping systems. Vents may be installed on most piping circuits at a minimum cost to prevent corrosion at liquid-vapor interfaces. These examples show how easily certain poor design problems may be overcome. There are other solutions, and probably many of these have not been recorded. There are many other situations, however, where remedial action is excessively expensive and no feasible action is possible.

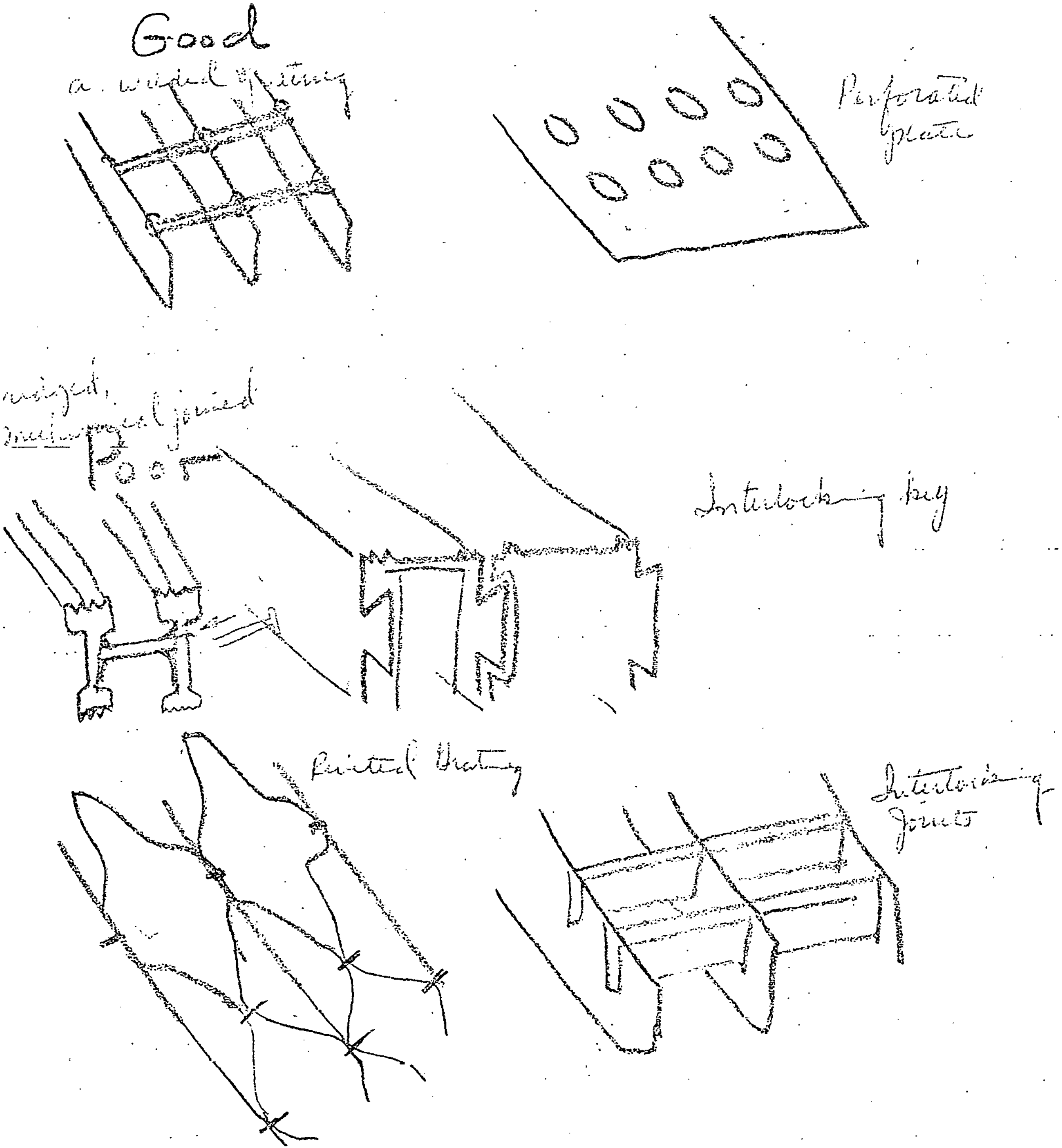

Figure 16. Effects of Grating Design on Corrosion

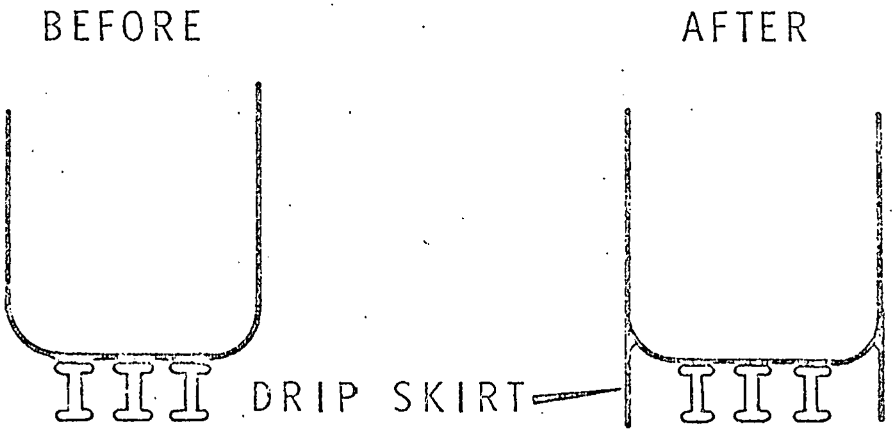

Figure 17. Tank Support and Protection

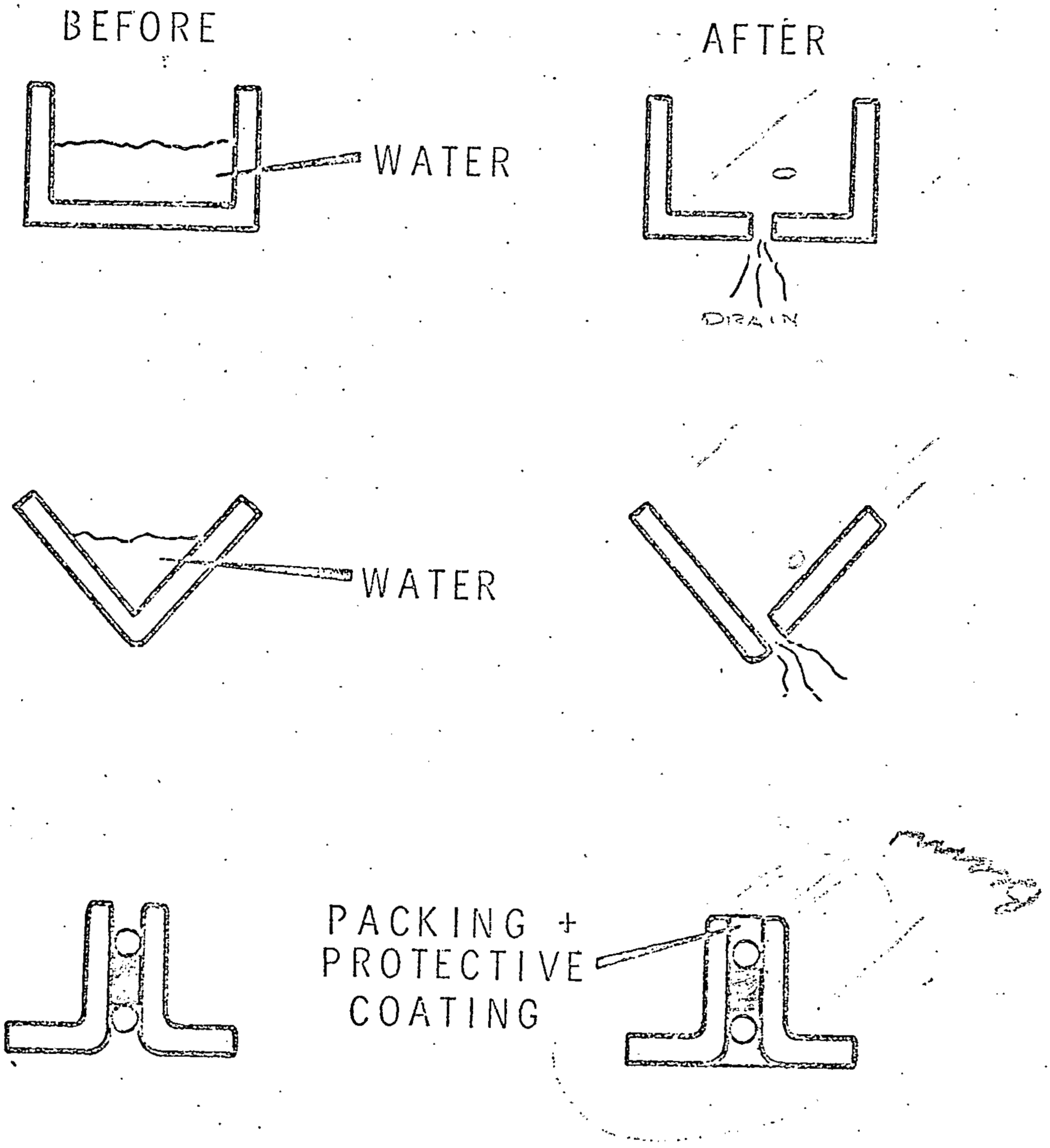

Figure 1[illegible] Protection for Structural Members

## Different System Requirements

The anticorrosion design principles that has been presented in the foregoing sections do not constitute an absolute philosophy that can be followed without thought. Different needs and different systems can lead to different approaches to the problem of how to design to avoid corrosion.

Perrigo(21) has noted that Burton's(6) recommendations for the use of stand pipes in process equipment cannot be readily applied to some nuclear systems. In the process industry system the standpipe was used to avoid velocity washing and attendant corrosion. The preferential deposition of radioactive material in such an area could, however, result in relatively high radiation fields and thus restrict contact maintenance. The ability to periodically flush the area in the nuclear case could have little effect on reducing radiation because of the tenacious nature of many of these deposits.

The need for large surface areas to promote more efficient heat and mass transfer also produce conflicts. Turbulent rather than laminar conditions are preferred and these can result in higher corrosion. Drainage and cleaning problems can be expected. The economics of operation must be balanced to produce the best design under these conditions.

## SUMMARY AND CONCLUSIONS

By applying simple and straightforward principles to the design of systems, buildings and equipment, operational corrosion problems may be reduced or avoided. These anticorrosion design principles are concerned with promoting the use of orientation, layout, and configuration to avoid the holdup of solutions, abrupt flow changes, impingement and stagnant areas. Climatic conditions and terrain are important siting considerations in reducing atmospheric corrosion of buildings and facilities. A determined effort is needed to broaden the understanding of anticorrosion design measures and principles because these are not widely known and recognized by designers and architects.

## ACKNOWLEDGEMENT

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