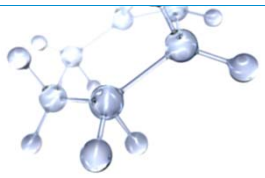
ExxonMobil Development

ATMOSPHERIC CORROSION INTEGRITY MANAGMENT



Michael Surkein

ExxonMobil Development Company

Houston, TX

OUTLINE

1. ATMOSPHERIC CORROSION
   - DOT REGULATIONS REGARDING ATMOSPHERIC CORROSION CONTROL
   - CAUSES / TYPES OF ATMOSPHERIC CORROSION
   - GENERAL PRACTICES FOR ABOVEGROUND CORROSION PREVENTION
2. PROTECTIVE COATINGS
   - COATING SELECTION FOR NEW CONSTRUCTION
   - MAINTENANCE OF ABOVEGROUND FACILITIES

CODE OF FEDERAL REGULATIONS

Gas Lines:

- 192.479 GENERAL ATMOSPHERIC CORROSION CONTROL
- 192.481 MONITORING OF ATMOSPHERIC CORROSION CONTROL

49 CFR 192.479

ATMOSPHERIC CORROSION CONTROL – GENERAL

- PIPELINE SECTIONS ABOVEGROUND INSTALLED AFTER 1971 MUST BE CLEANED AND COATED TO PREVENT CORROSION
- THE EXCEPTION TO THIS RULE IS IF AN OPERATOR CAN SHOW THAT THE LINE IS IN A NON-CORROSIVE ENVIRONMENT

49 CFR 192.479

FOR ABOVEGROUND PIPELINE SECTIONS INSTALLED BEFORE 1971 THE OPERATOR SHALL:

- DETERMINE AREAS OF ATMOSPHERIC CORROSION
- HAVE THESE AREAS REMEDIATED BY APPROPRIATE MEANS
- BE CLEANED AND COATED/JACKETED TO PREVENT FURTHER CORROSION

49 CFR 192.481

MONITORING ATMOSPHERIC CORROSION ON GAS LINES

- ONSHORE PIPELINES MUST BE RE-EVALUATED EVERY THREE YEARS
- OFFSHORE PIPELINES MUST BE RE-EVALUATED ONCE PER YEAR
- NO SPECIFICS ON EVALUATION DATA

LNG AND LIQUIDS

- 193.2627 – LNG
  - COMPONENTS SUBJECT TO ATMOSHPERIC CORROSION MUST EITHER BE CONSTRUCTED FROM CORROSION-RESISTANT MATERIAL OR COATED
- 195.416 – HAZ LIQUIDS
  - CLEAN AND COAT LINES SUBJECT TO ATMOSPHERIC CORROSION

TYPICAL ABOVEGROUND AREAS

- TANK FARMS
- BRIDGE CROSSINGS
- DOCKS
- METERING STATIONS
- PIERS
- REFINERIES
- STORAGE FACILITIES

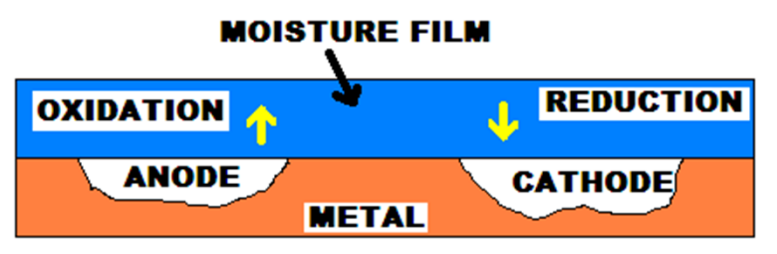
Coastal/Offshore Structures

Offshore Severe Weathering

TYPES / CAUSES OF ATMOSPHERIC CORROSION

ATMOSPHERIC CORROSION REQUIREMENTS

- ANODE
- CATHODE
- METALLIC PATH
- ELECTROLYTE



UNIFORM CORROSION

- LAYER OR FLAKING CORROSION PRODUCT

GALVANIC

FACTORS AFFECTING ATMOSPHERIC CORROSION

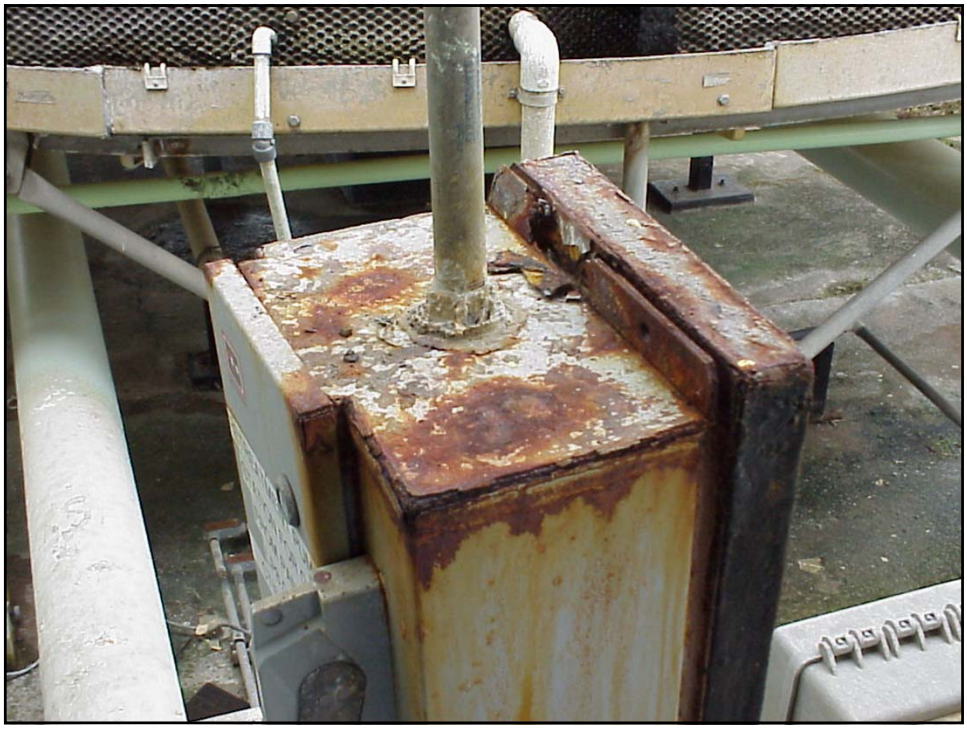
- MOISTURE - MOST IMPORTANT FACTOR
- TEMPERATURE

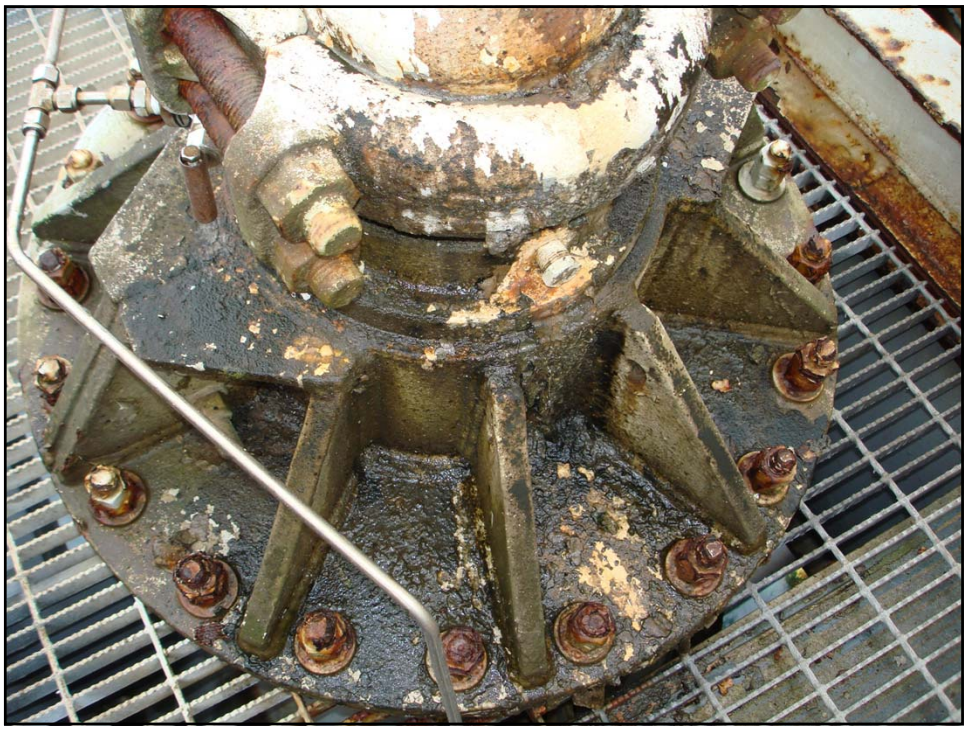
  AFFECTS

  - RELATIVE HUMIDITY/DEW POINT
  - TIME OF WETNESS
  - KINETICS OF CORROSION REACTION
  - CYCLIC CONDITIONS

- AIR POLLUTANTS – chlorides, sulfur species
- FOREIGN MATTER ACCUMULATION


Z4-6"





ATMOSPHERIC CORROSION CONTROL

HOW IS AN ABOVEGROUND PIPELINE DIFFERENT FROM A BELOW GRADE PIPELINE?

1. CATHODIC PROTECTION IS NOT POSSIBLE
2. EASY VISUAL INSPECTION / ACCESS
3. AESTHETICS MORE IMPORTANT
4. WEATHERING CONDITIONS MUCH DIFFERENT THAN BURIAL CONDITIONS

MATERIALS SELECTION

- **SELECT FOR INHERENT CORROSION RESISTANCE**
  - ALLOYS
  - NON-METALLIC MATERIALS
- **HIGHER INITIAL COST**
- **LOWER MAINTENANCE COST**

METAL ALLOYS

- **CARBON STEEL**
- **WEATHERING STEEL (HSLA)**
- **GALVANIZED STEEL**
- **STAINLESS STEEL**
- **ALUMINUM ALLOYS**
- **COPPER ALLOYS**
- **CRA (corrosion resistant alloys)**

ATMOSPHERIC CORROSION RATES

	RURAL	URBAN	INDUSTRIAL	MARINE
CARBON STEEL	4-65	23-71	26-175	26-104
STAINLESS STEEL		0.002-0.01	0-0.02	0-0.03
COPPER	0.4-0.5		1-3	0.2-1.5
ALUMINUM	0-0.1	1	1-13	0.4-0.6
GALVANIZED STEEL	0.2-3.0	2-16	2-16	0.5-0.6

Table 1 — Atmospheric-corrosivity categories and examples of typical environments

Corrosivity category	Mass loss per unit surface/thickness loss (after first year of exposure)				Examples of typical environments in a temperate climate (informative only)	
	Low-carbon steel		Zinc		Exterior	Interior
	Mass loss g/m²	Thickness loss µm	Mass loss g/m²	Thickness loss µm		
C1 very low	≤ 10	≤ 1,3	≤ 0,7	≤ 0,1	—	Heated buildings with clean atmospheres, e.g. offices, shops, schools, hotels.
C2 low	> 10 to 200	> 1,3 to 25	> 0,7 to 5	> 0,1 to 0,7	Atmospheres with low level of pollution. Mostly rural areas.	Unheated buildings where condensation may occur, e.g. depots, sports halls.
C3 medium	> 200 to 400	> 25 to 50	> 5 to 15	> 0,7 to 2,1	Urban and industrial atmospheres, moderate sulfur dioxide pollution. Coastal areas with low salinity.	Production rooms with high humidity and some air pollution, e.g. food-processing plants, laundries, breweries, dairies.
C4 high	> 400 to 650	> 50 to 80	> 15 to 30	> 2,1 to 4,2	Industrial areas and coastal areas with moderate salinity.	Chemical plants, swimming pools, coastal ship- and boatyards.
C5-1 very high (industrial)	> 650 to 1 500	> 80 to 200	> 30 to 60	> 4,2 to 8,4	Industrial areas with high humidity and aggressive atmosphere.	Buildings or areas with almost permanent condensation and with high pollution.
C5-M very high (marine)	> 650 to 1 500	> 80 to 200	> 30 to 60	> 4,2 to 8,4	Coastal and offshore areas with high salinity	Buildings or areas with almost permanent condensation and with high pollution.

NOTE 1 The loss values used for the corrosivity categories are identical to those given in ISO 9223.
NOTE 2 In coastal areas in hot, humid zones, the mass or thickness losses can exceed the limits of category C5-M. Special precautions must therefore be taken when selecting protective paint systems for structures in such areas.

ISO 12944 Part 2 (1998) Corrosion Protection of Steel Structures by Protective Paint Systems

Part 2: Classification of Environments

STAINLESS (?) STEEL

- 300-SERIES, CHROMIUM STAINLESS STEELS (304, 316) MOST COMMON
- IN MARINE ENVIRONMENT, STAINLESS STEELS WILL PIT AND CORRODE
- 300 SERIES IS SUSCEPTIBLE TO CHLORIDE STRESS CRACKING
- PAINTING OF 300 SERIES COMMON

NON-METALLIC MATERIALS

- **EXAMPLES**
  - **- PLASTIC INSTEAD OF METAL PIPE**
  - **- FIBERGLASS BOLTS INSTEAD OF STEEL**
- **CONSIDERATIONS**
  - **- STRENGTH**
  - **- ENVIRONMENTAL DETERIORATION**
  - **- COST**
  - **- INSTALLATION DETAILS**

FIBERGLASS MANHOLE

COATINGS – MOST COMMON CORROSION CONTROL METHOD USED FOR ABOVEGROUND AREAS

COATINGS

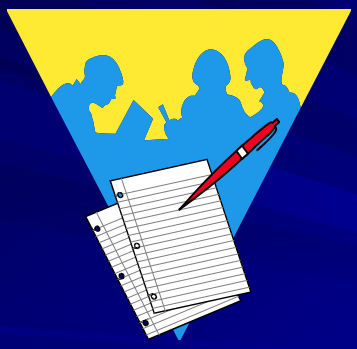
- PROVIDE BARRIER BETWEEN SURFACE AND ENVIRONMENT
- SOME (ZINC PRIMERS) PROVIDE SOME SACRIFICIAL CP AT GOUGES/DEFECTS
- ATTRIBUTES

  - WEATHERABILITY
  - CORROSION PROTECTION
  - APPEARANCE RETENTION- AESTICS
  - MAINTAINABILITY

PIPELINE COATINGS VS. ATMOSPHERIC COATINGS

- PIPELINE COATINGS ARE THICK TO AVOID PHYSICAL DAMAGE – ATMOSPHERIC COATINGS NOT NORMALLY AS THICK
- PIPELINE COATINGS ARE SUPPLEMENTED BY CP – ATMOSPHERIC COATINGS ARE NOT
- PIPELINE COATINGS ARE DIFFICULT TO REPAIR – ATMOSPHERIC COATINGS ARE NOT

Coating Specifications



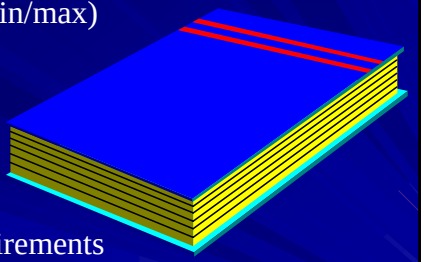
Basic Philosophy

The best coating known will only perform well if it is ...

- In the right application
- Applied to a properly prepared surface
- Applied properly
- Handled properly
- Inspected properly

COATING SPECIFICATION COMPONENTS

- Surface preparation materials and requirements
- Specified system: primer, build coat, top coat
- Dry film thickness of each coat (min/max)
- Total dry film thickness
- Application methods
- Inspection requirements
- Safety/Health/Environmental requirements
- General requirements
  - Define vendor and subcontractor responsibilities and their interrelationship
  - Areas not to be coated



COATING INSPECTION DURING APPLICATION IS *VERY IMPORTANT*

- ENSURES THAT SPECIFICATIONS ARE MET
- CONDUCT TESTS
- KEEPS RECORDS
- APPROXIMATELY 10% OF TOTAL PAINTING COST
- GOOD INSPECTION PAYS FOR ITSELF IN IMPROVED LIFE OF COATING

Typical Shipyard Construction

EFFECTIVE COATING SYSTEMS

EFFECTIVE COATING SYSTEMS

NEW CONSTRUCTION:

- INORGANIC ZINC PRIMER (OR INORGANIC)
- EPOXY BUILD COAT
- POLYURETHANE TOPCOAT

- BEST SYSTEM FOR LONG TERM CORROSION RESISTANCE AND COLOR/GLOSS RETENTION

FUNCTIONS OF SPECIFIC COATS

Primer

- Adhesion to surface. Coating wets surface.
- Corrosion inhibition with inhibitive pigments
- Sacrificial protection with zinc pigments
- Protect surface preparation to help adhesion of additional coats

Build Coat

- Additional thickness
- Chemical resistance, low moisture transmission
- Adhesion between primer and top coat

Top Coat

- Weather and/or chemical resistance
- Color and gloss
- Mildew or biological resistance
- Wear or abrasion resistance

WEATHERING TESTS

LIQUID APPLIED COATINGS

STANDARD INEXPENSIVE MAINTENANCE COATINGS

OIL BASED ALKYD

SILICONE ALKYD

ACRYLIC

- **ONE COMPONENT, LESS COSTLY TO APPLY**
- **GENERALLY POOR WEATHERING RESISTANCE, LOWER SERVICE LIFE**
- **SOMETIMES, ALKYD OR ACRYLIC TOPCOATS OVER EPOXY PRIMERS OFFER EXCELLENT ECONOMIC CHOICE**

LIQUID APPLIED COATINGS

HIGH PERFORMANCE COATINGS

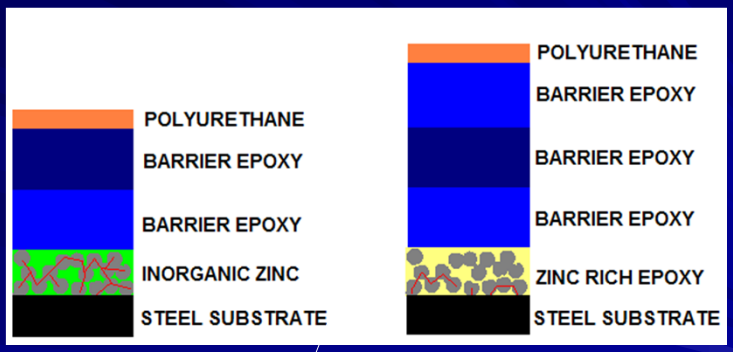
EPOXY

POLYURETHANE

ZINC RICH

- **HIGHER INITIAL COST**
- **CAN BE MORE SENSITIVE TO SURFACE PREPARATION**
- **LONG LIFE IF APPLIED CORRECTLY**
- **LIKELY LOWER LIFE CYCLE COST**

INORGANIC ZINC VS. ZINC RICH EPOXY



INORGANIC ZINC: INTERCONNECTED NETWORK OF GALVANIC PROTECTION

ZINC-RICH EPOXY: PARTIAL NETWORK OF GALVANIC PROTECTION

HIGH-TEMPERATURE SYSTEMS

- GENERALLY INORGANIC SYSTEMS (SILICONES, ZINCS) NEEDED ABOVE 400F
- HIGH TEMP SYSTEMS ARE BRITTLE, CAN BE SUBJECT TO CRACKING AND DISBONDING – BAD NEWS IF WATER IS TRAPPED UNDER INSULATION AND COATING HAS FAILED
- SOME NEED HEAT CURE

UV DAMAGE AND COATINGS

- POLYURETHANES ARE RESISTANT TO UV – GOOD AS TOPCOATS
- FBE AND LIQUID EPOXIES WILL CHALK IN UV, BUT LOSS TENDS TO BE LIMITED TO LESS THAN 1 MPY OR LESS, DEPENDING ON OTHER WEATHERING
- THERMOPLASTICS (POLYETHYLENE, POLYPROPYLENE) DEGRADE AND CAN SPLIT IN UV – NOT GOOD UNLESS UV STABILIZED OR COATED OVER

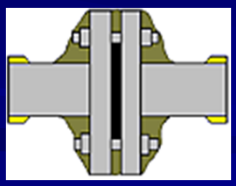
ODD SHAPED SURFACES

- FLANGES
- BOLTS
- VALVE BODIES

NO DUCT TAPE ALLOWED!

FILL-IN SYSTEMS FOR CREVICES

- PETROLATUM FILLERS AND TAPES – CAN BE APPLIED DIRECTLY ON WET SURFACES, BUT WILL MOVE AT HIGH TEMPERATURES
- WAX TAPES– CHECK UPPER SERVICE TEMPERATURE
- EPOXY CAULKS (BUT DON'T GLUE FLANGES TOGETHER OR GLUE VALVES OPEN/SHUT)
- IS IT A GOOD APPROACH TO COVER UP?



ORGANIC BARRIER COATINGS

PIPELINE COATINGS

- FBE
- COAL TAR ENAMEL - RARELY USED TODAY
- ASPHALT ENAMEL - RARELY USED TODAY
- EPOXIES - LIQUID
- EXTRUDED POLYETHYLENE (TWO LAYER)
- TAPE WRAPS
- 3-LAYER POLYOLEFINS (PE & PP)

FOR ABOVEGROUND SERVICE, MOST OF THESE ARE NOT THE BEST CHOICE

SELECT COATING TO BE UV RESISTANT

METALLIC (SACRIFICIAL) COATINGS

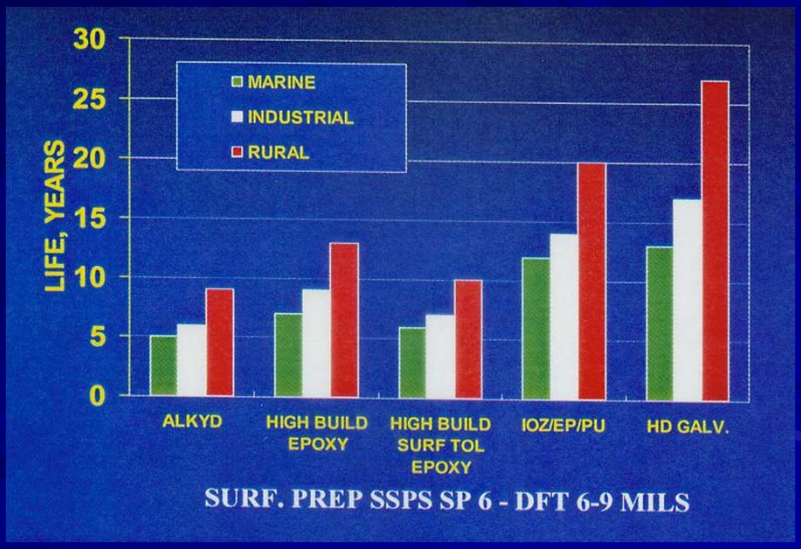
- ZINC – GALVANIZED, ELECTROPLATE, METALLIZE
- ALUMINUM – HOT DIP, METALLIZE (TSA = thermal spray aluminum), LIQUID
- ALUMINUM-ZINC – HOT DIP, METALLIZE
- CADMIUM (ELECTROPLATE) – NOT USED MUCH
- ZINC RICH (LIQUID APPLIED)

THERMAL SPRAY ALUMINUM

GALVANIZING

- HOT-DIP GALVANIZING MOST COMMON
- TOPCOATING WITH DTM ACRYLIC OR BETTER ENABLES LONG SERVICE LIFE
- RATES OF ZINC LOSS ARE WELL ESTABLISHED FOR DIFFERENT ENVIRONMENTS

STRUCTURE LOCATION



NO COATING LASTS FOREVER

MAINTENANCE AND EVENTUAL REPLACEMENT WILL BE NEEDED

After Application Trouble Spots

MECHANICAL DAMAGE

THIN EDGE & CORROSION

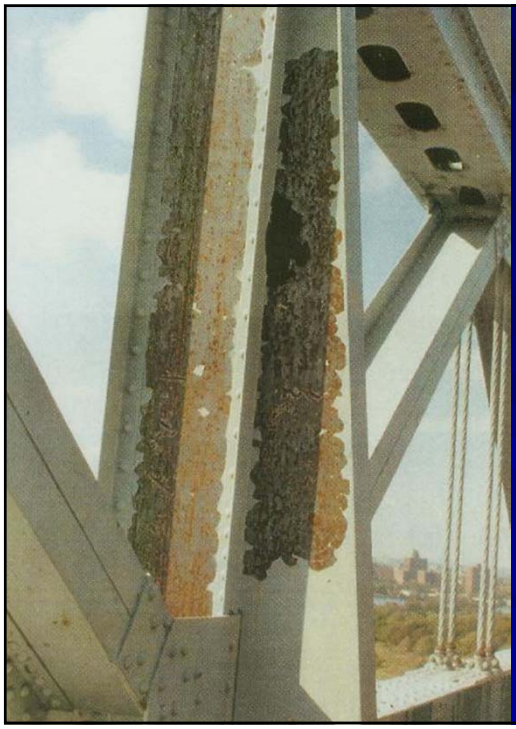
After Application Trouble Spots

POORLY PREPARED WELD

EMBEDDED GRIT RUSTING

MAINTENANCE COATINGS

- GENERALLY FALL INTO CATEGORY OF "SURFACE TOLERANT" EPOXIES, DTM ACRYLICS
- GETTING SURFACE CLEAN (DE-GREASED, DE-SALTED, LOOSE RUST AND LOOSE COATING REMOVED) IS MOST CRITICAL STEP – POWER WASHING OFTEN USED
- EPOXY WITH POLYURETHANE TOPCOAT MOST EFFECTIVE SYSTEM



SUBSTRATE – IS GOOD SURFACE PREPARATION POSSIBLE?

SURFACE PREPARATION

- **MOST IMPORTANT PART OF COATING APPLICATION**
- **PURPOSE**
  - **REMOVE SURFACE CONTAMINATION AND CREATE ANCHOR PATTERN**

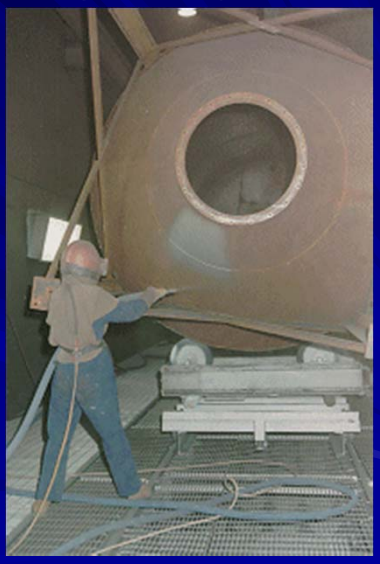
USE BEST POSSIBLE METHOD + COATING WHICH IS APPROPRIATE FOR THAT SURFACE PREP

SURFACE PREPARATION

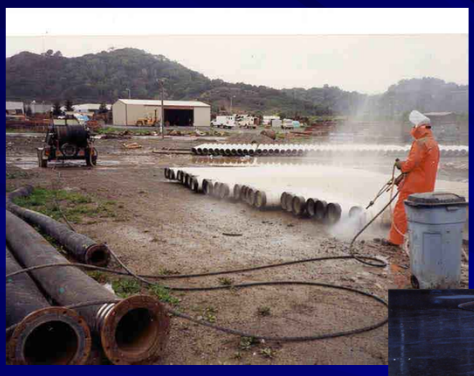
- Abrasive Blast (Dry or Wet)
  - White Metal > Near White > Commercial > Brush Blast
- Water Blast
- Water Jetting
- Power Tool Cleaning
- Hand Tool Cleaning
- Solvent Cleaning
  - Organic or alkaline solvents, detergents, steam

Surface prep gets better in this direction

ABRASIVE BLASTING



WET BLASTING



Vacuum Blast

WANT TO AVOID THIS!

INSPECTION AND MAINTENANCE

REASONS FOR COATING MAINTENANCE

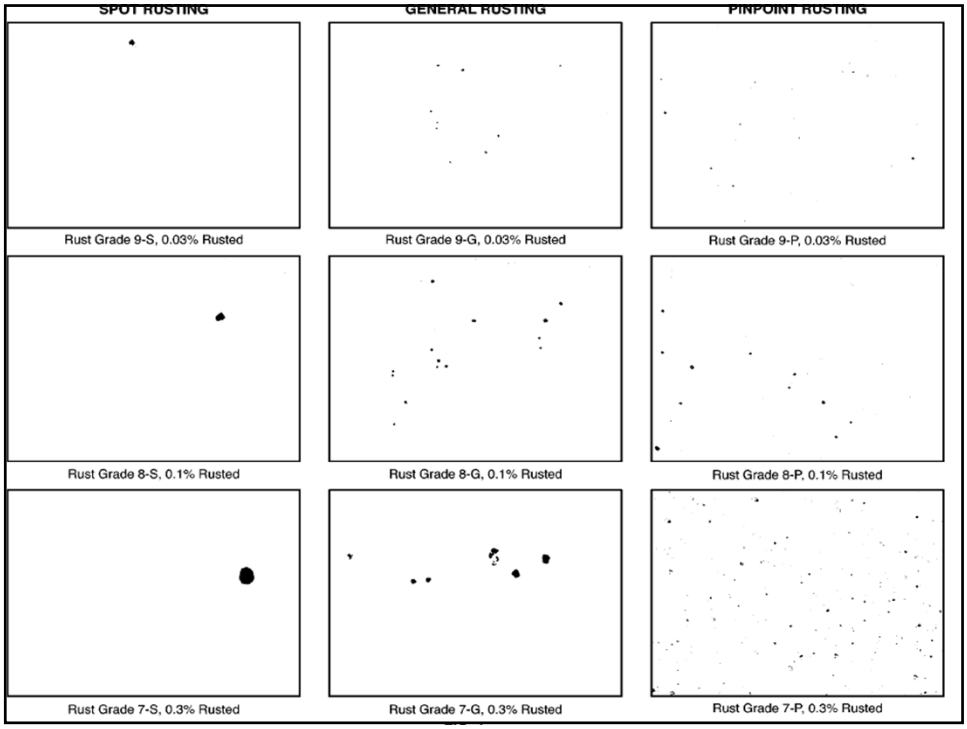
- A GOOD COATING, IF PROPERLY MAINTAINED, SHOULD LAST 10-12 YEARS BEFORE REQUIRING MAJOR RE-COATING.
- PERIODIC VISUAL COATING INSPECTION AND MINOR REPAIR IS NECESSARY TO IDENTIFY AND MAP AREAS OF COATING FAILURE TO AVOID CATASTROPHIC RESULTS.
- REPAIR ON A ROUTINE BASIS PROLONGS THE LIFE OF THE COATING AND POSTPONES THE NEED FOR FULL RE-COATING.

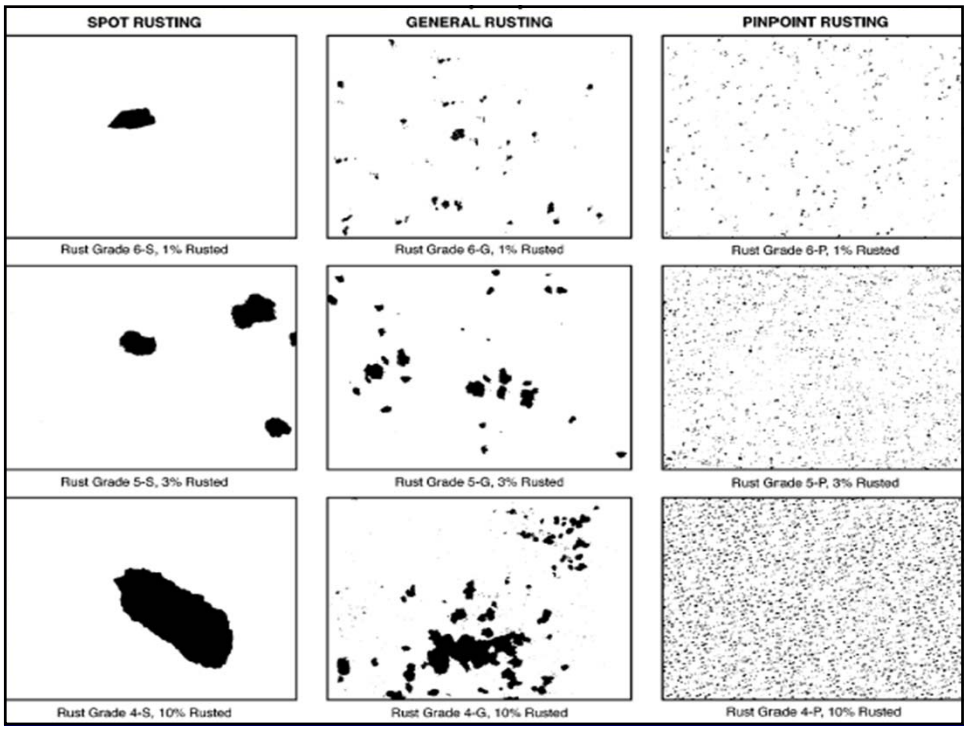
INSPECTION – DOCUMENTATION OF CONDITION

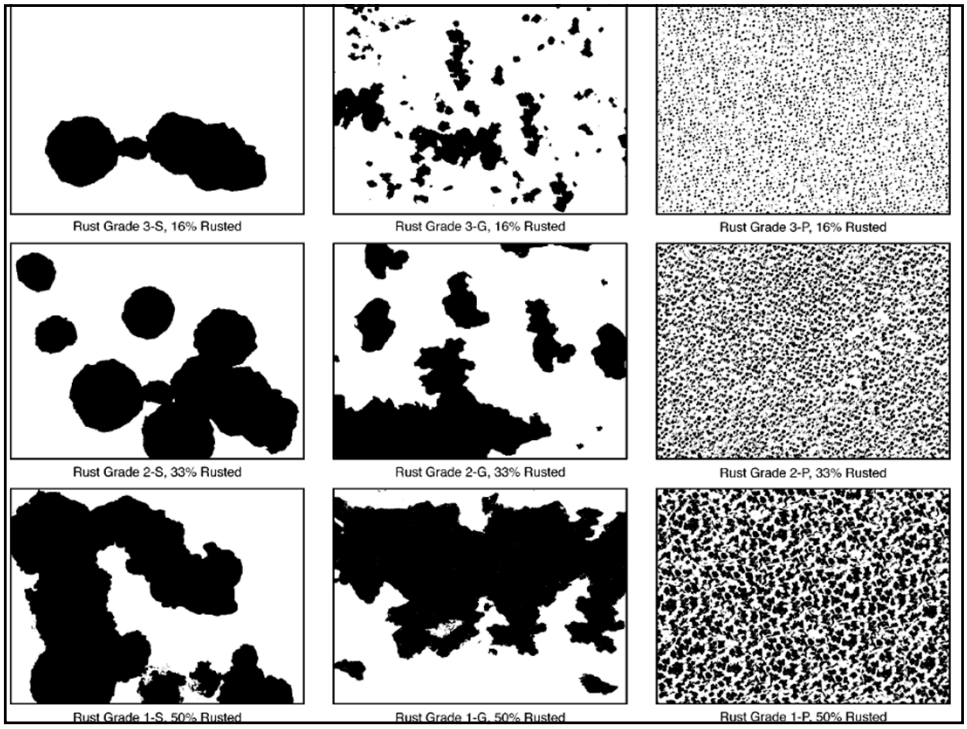
- **WRITTEN DESCRIPTION**
  - PHOTOGRAPHS HELPFUL
- **TYPE OF DEFECT**
- **LOCATION**
- **DEPTH OF CORROSION**
- **EXTENT OF CORROSION**

ASTM D610

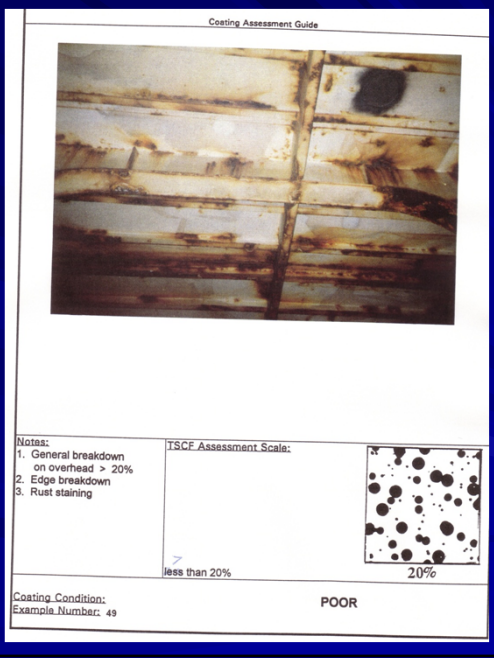
- CATEGORIZE EXTENT OF RUSTING
- VISUAL “STANDARDS” TO HELP RATE
- BASED ON TYPE OF RUST, PERCENT AREAS


SPOT RUSTING
GENERAL RUSTING
PINPOINT RUSTING
Rust Grade 9-S, 0.03% Rusted
Rust Grade 9-G, 0.03% Rusted
Rust Grade 9-P, 0.03% Rusted
Rust Grade 8-S, 0.1% Rusted
Rust Grade 8-G, 0.1% Rusted
Rust Grade 8-P, 0.1% Rusted
Rust Grade 7-S, 0.3% Rusted
Rust Grade 7-G, 0.3% Rusted
Rust Grade 7-P, 0.3% Rusted


SPOT RUSTING
GENERAL RUSTING
PINPOINT RUSTING
Rust Grade 6-S, 1% Rusted
Rust Grade 6-G, 1% Rusted
Rust Grade 6-P, 1% Rusted
Rust Grade 5-S, 3% Rusted
Rust Grade 5-G, 3% Rusted
Rust Grade 5-P, 3% Rusted
Rust Grade 4-S, 10% Rusted
Rust Grade 4-G, 10% Rusted
Rust Grade 4-P, 10% Rusted



Example of Coating Breakdown



SUMMARY

- **ABOVEGROUND CORROSION CONTROL IS VERY DIFFERENT FROM BELOW GRADE CONTROL**
- **PROPER SELECTION, APPLICATION, INSPECTION, AND MAINTENANCE OF ORGANIC COATINGS IS THE MOST COST EFFECTIVE WAY TO CONTROL CORROSION IN MOST CASES**
- **CHANGE OF DESIGN AND USE OF ALTERNATIVE MATERIALS SOMETIMES APPROPRIATE**

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MIKE SURKEIN
ExxonMobil Development Co.
Houston, TX
281-654-4821
michael.surkein@exxonmobil.com