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TANK SPECIFICATIONS

A storage tank was inspected and several through holes were observed in the bottom plates and annular plates. The shell is in OK. In the present condition, the tank no longer can be used safely in the specified operational parameters. The inspector recommends repairs to the affected areas. But even with all the repairs, there is a concern about the level of risk present if the tank runs for another 5 years. An RBI study was done, and here is an estimate of the risk of the tank serviceability as per API 580 & 581.

Diameter: 10.7m

Product Stored: Crude Oil

Roof: Fixed

Liquid Height: 13 meter

Type of soil: Coarse sand

Year of construction: 1971

Product specific gravity: 0.82

Internal pressure: Atmospheric

Bottom/ annular plate thickness: 7.5mm / 10mm.

Shell plate thickness: 10mm to 6mm (bottom to top shell course)

No of shell courses: 8 nos.

Material of construction: Not known (assumed to be ASTM A 36)

Release prevention barrier = No

CONSEQUENCE OF FAILURE CALCULATION

This example to obtain the COF of the failure of the bottom of a tank is modeled according to API 581 RP can be found in pages 589-607 of API 581 RP 2ND edition

NOTE: We will only consider Financial cost to the environment, component damage and business cost operation.

+++++DETERMINE THE REPRESENTATIVE FLUID AND ASSOCIATED PROPERTIES++++

STEP 1.1 – Select the representative fluid from Table 7.1.

In this case, the representative fluid is crude with the following properties

Molecular weight = 280

STEP 1.2 – Determine the representative fluid properties including the density, ρ_l, and dynamic viscosity, μ_l, from Table 7.1.

Table 7.1M – Fluids and Fluid Properties for Atmospheric Storage Tank Consequence Analysis

Fluid	Level 1 Consequence Analysis Representative Fluid	Molecular Weight	Liquid Density (kg/m^3)	Liquid Dynamic Viscosity (N-s/m^2)
Gasoline	C6-C8	100	684.018	4.01E-3
Light Diesel Oil	C9-C12	149	734.011	1.04E-3
Heavy Diesel Oil	C13-C16	205	764.527	2.46E-3
Fuel Oil	C17-C25	280	775.019	3.69E-2
Crude Oil	C17-C25	280	775.019	3.69E-2
Heavy Fuel Oil	C25+	422	900.026	4.60E-2
Heavy Crude Oil	C25+	422	900.026	4.60E-2

Liquid density = 775.019 kg/m3
Liquid Dynamic Viscosity = 0.0369N-s/m2

STEP 1.3 – Calculate the hydraulic conductivity for water by averaging the upper and lower bound hydraulic conductivities provided in Table 7.2 for the soil type selected using Equation (3.219).

Type of soil: coarse sand
Hydraulic Conductivity for Water Lower Bound= 1e-1cm/s
Hydraulic Conductivity for Water Lower Bound= 1e-2cm/s
Soil Porosity = 0.33
Conversion factor C31 = 864

$$k_{h,water} = C_{31}\frac{\left(k_{h,water-lb} + k_{h,water-ub}\right)}{2} \qquad (3.219)$$

Then, hydraulic conductivity for water = 47.52

STEP 1.4 – Calculate the fluid hydraulic conductivity, $k_{h,prod}$, for the fluid stored in the tank using Equation (3.217) based on the density, ρ_l, and dynamic viscosity, μ_l, from STEP 1.2 and the hydraulic conductivity for water, $k_{h,water}$, from STEP 1.3.

$$k_{h,prod} = k_{h,water}\left(\frac{\rho_l}{\rho_w}\right)\left(\frac{\mu_w}{\mu_l}\right) \quad (3.217)$$

Density of water = 1000kg/m3

Dynamic viscosity of water = 0.001002 N-s/m2

Density of the product = 775.019kg/m3

Dynamic viscosity of the product = 0.0369N-s/m2

$k_{h,prod}$ = 1

STEP 1.5 – Calculate the product seepage velocity, $vel_{s,prod}$, for the fluid stored in the tank using Equation (3.218) based on fluid hydraulic conductivity, $k_{h,prod}$, from STEP 1.4 and the soil porosity provided in Table 7.2

$$vel_{s,prod} = \frac{k_{h,prod}}{p_s} \quad (3.218)$$

$vel_{s,prod}$ = 3.03

++++++RELEASE HOLE SIZE SELECTION+++++++

STEP 2.1 Determine the release hole size, d_n, from Table 7.3 for tank shell courses and from Table 7.4 for tank bottoms.

Table 7.4M – Release Hole Sizes and Areas – Tank Bottoms

Release Hole Number	Release Hole Size	Release Prevention Barrier?	Range of Hole Diameters (mm)	Release Hole Diameter (mm)
1	Small	Yes	0 – 3.175	$d_1 = 3.175$
		No	0 – 12.7	$d_1 = 12.7$
2	Medium	NA	0	$d_2 = 0$
		NA	0	
3	Large	NA	0	$d_3 = 0$
		NA	0	
4	Rupture	Yes	> 3.175	$d_4 = 1000\left(\frac{D_{tank}}{4}\right)$

d_1 = 12.7mm (note that d2 = 0, d3 = 0, drupture=etc.)

STEP 2.2 – Determine the generic failure frequency, gff_n, for the n^{th} release hole size from Part 2, Table 4.1, and the total generic failure frequency from this table or from Equation (3.220).

Table 4.1 – Suggested Component Generic Failure Frequencies (gff)[1 thru 8]

Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Compressor	COMPC	8.00E-06	2.00E-05	2.00E-06	0	3.00E-05
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04

$$gff_{tot} = \sum_{n=1}^{4} gff_n \qquad (3.220)$$

Gffsmall = 7.2E-4
Gffrupture = 2e-6
Gfftotal = 7.2E-4

+++++++++RELEASE RATE++++++++

STEP 3.1 – For each release hole size, determine the height of the liquid, h_{liq}, above the release hole size, d_n.

h_{liq} =13m

STEP 3.2 – For each release hole size, determine the number of release holes, $n_{rh,n}$, from Table 7.5.

Table 7.5 – Number of Release Holes as a Function of Tank Diameter

Tank Diameter (m [ft])	Number of Release Holes With or Without a Release Prevention Barrier		
	Small	Medium	Large
30.5 [100]	1	0	0

$$n_{rh,1} = \max\left[\text{nint}\left[\left(\frac{D}{C_{36}} \right)^2 \right], 1 \right]$$

$n_{rh,n}$ = 1

STEP 3.3 – Determine the hydraulic conductivity of the stored liquid, k_h, from STEP 1.3.

Same as in step 1.3

STEP 3.4 – For each release hole size, determine the flow rate, W_n, using Equation (3.222) or Equation (3.223), as applicable. The liquid height, h_{liq}, to use in this calculation is determined as follows:

1) The Tank has an RPB – $h_{liq} = 0.0762\text{m}\ [.25\text{ft}]$
2) The Tank does not have an RPB – $h_{liq} = \textit{Actual Product Height}$

$$W_n = C_{35} \cdot C_{qo} \cdot d_n^{0.2} \cdot h_{liq}^{0.9} \cdot k_h^{0.74} \cdot n_{rh,n} \qquad for\ k_h \le C_{34} \cdot d_n^2 \qquad (3.223)$$

C35 = 2.382

Cqo = 0.21

Hliq = 13

Kh = 1

Nrh,n = 1

Then, W_n = 8.36barrels/day

+++++ESTIMATE THE INVENTORY VOLUME AVILABLE FOR RELEASE+++++

STEP 4.1 – Calculate liquid volume in the tank in m^3 [ft^3] using Equation (3.229).

$$Lvol_{total} = \left(\frac{\pi D_{tank}^2}{4} \right) \cdot h_{liq} \qquad (3.229)$$

$Lvol_{total}$ =1168.96m3

STEP 4.2 – Calculate the total tank volume in barrels using Equation (3.230).

$$Bbl_{total} = \frac{Lvol_{total}}{C_{13}} \quad (3.230)$$

C13 = 6.29

Bbl_{total} = 185.84Barrels

++DETERMINE THE RELEASE RATE AND VOLUME FOR THE CONSEQUENCE ANALYSIS++

STEP 7.1 – For each release hole size, determine the release rate, $rate_n$, using Equation (3.231) where the release rate, W_n, is from STEP 3.5.

$rate_n$ = W_n = 8.36barrels/day (3.231)

STEP 7.2 – Determine the leak detection time, t_{ld}, as follows:

$t_{ld} = 360$ days for a tank without a release prevention barrier.

STEP 7.3 – For each release hole size, calculate the leak duration, ld_n, of the release using Equation (3.235) based on the release rate, $rate_n$, from STEP 7.1, the leak detection time, t_{ld}, from STEP 7.2, and the total volume, Bbl_{total}, from STEP 4.2

$$ld_n = \min\left[\left\{\frac{Bbl_{total}}{rate_n}\right\},\ t_{ld}\right] \quad (3.235)$$

Bbltotal/raten = 22.215days

Then, ld_n = 22.215days

STEP 7.4 – For each release hole size, calculate the release volume from leakage, Bbl_n^{leak}, using Equation (3.236) based on the release rate, $rate_n$, from STEP 7.1, the leak duration, ld_n, from STEP 7.3, and the total volume, Bbl_{total}, from STEP 4.2.

$$Bbl_n^{leak} = \min\left[\left\{rate_n \cdot ld_n\right\},\ Bbl_{avail,n}\right] \quad (3.236)$$

Bbl_n^{leak} = min ((8.36*22.215), 185.4)

Then Bbl_n^{leak} = 185.4Barrels

STEP 7.5 – For each release hole size, calculate the release volume from a rupture, $Bbl_n^{rupture}$, using Equation (3.237) based on the total volume, Bbl_{total}, from STEP 4.2. 185.75

$$Bbl_n^{rupture} = Bbl_{total} \quad (3.237)$$

$Bbl_n^{rupture}$ = 185.4Barrels

STEP 12.1 – Determine the following parameters.

1) P_{lvdike} – percentage of fluid leaving the dike
2) P_{onsite} – percentage of fluid that leaves the dike area but remains on-site
3) $P_{offsite}$ – percentage of fluid that leaves the dike area and the site area

Let´s choose

1) P_{lvdike} = 30
2) P_{onsite} = 50
3) $P_{offsite}$ = 20

STEP 12.2 – Determine the environmental sensitivity, and based on the environmental sensitivity establish C_{indike}, $C_{ss-onsite}$, $C_{ss-offsite}$, and C_{water} from Table 7.6.

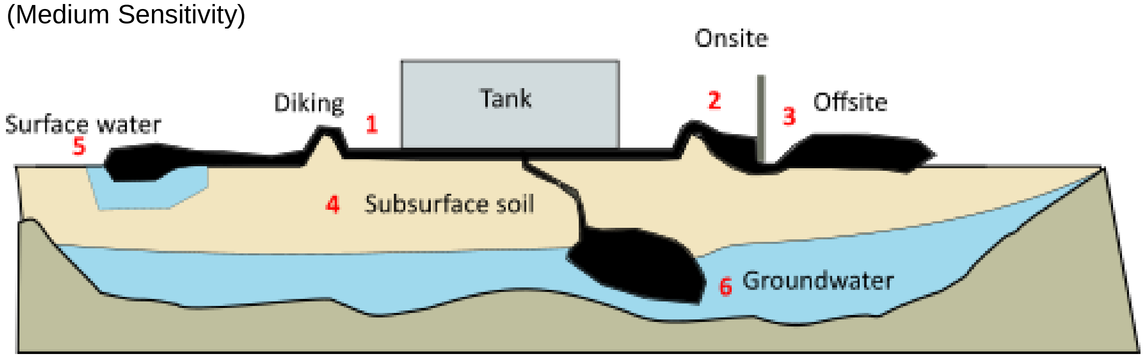
Table 7.6 – Cost Parameters Based on Environmental Sensitivity

Location (1)	Description	Environmental Sensitivity		
		Low (US$/bbl)	Medium (US$/bbl)	High (US$/bbl)
1	C_{indike} – Environmental cost for product located in the dike area	10	10	10
2	$C_{ss-onsite}$ – Environmental cost for product located in surface soil located on-site	50	50	50
3	$C_{ss-offsite}$ – Environmental cost for product located in surface soil located off-site	100	250	500
4	$C_{subsoil}$ – Environmental cost for product located in subsoil	500	1500	3000
5	$C_{groundwater}$ – Environmental cost for product located in groundwater	1000	5000	10000
6	C_{water} – Environmental cost for product in surface water	500	1500	5000

Notes:
1. See Figure 7.1
2. The values shown above are estimates. The end user should decide if these values are appropriate for the specific application.

Then
Cindike = 10
Css-onsite = 50
Css-offsite = 250
Csubsoil = 1500
Cgroundwater = 5000
Cwater = 1500

(Medium Sensitivity)



STEP 12.3 – Determine the seepage velocity of the product, $vel_{s,prod}$, using Equation (3.218).

$$vel_{s,prod} = \frac{k_{h,prod}}{p_s} \quad (3.218)$$

Kh,prod = 1
p_s = 0.33
Then $vel_{s,prod}$ = 3.03

STEP 12.4 – Determine the total distance to the ground water underneath the tank, s_{gw}, and the time to initiate leakage to the ground water, t_{gl}.

According to information from the neighbors, s_{gw} = 5m

$$t_{gl} = \frac{s_{gw}}{vel_{s,prod}} \quad (3.252)$$

Vels,prod = 3.03
Then, t_{gl} = 1.649days

STEP 12.5 – For each release hole size, determine the volume of the product in the subsoil and ground water where the leak detection time, t_{ld}, is determined in STEP 7.2.

$$Bbl^{leak}_{groundwater,n} = 0 \qquad for\ t_{gl} \le t_{ld} \tag{3.254}$$

$$Bbl^{leak}_{subsoil,n} = Bbl^{leak}_{n} - Bbl^{leak}_{groundwater,n} \tag{3.255}$$

Bblleakgroundwater,n = 0, because tgl = 22.215 < tld = 360

Bbleaksubsoil,n = 185.48

STEP 12.6 – For each release hole size, determine the environmental financial consequence of a leak, $FC^{leak}_{environ}$.

$$FC^{leak}_{environ} = \frac{\sum_{n=1}^{3}\left(Bbl^{leak}_{groundwater,n} \cdot C_{groundwater} + Bbl^{leak}_{subsoil,n} \cdot C_{subsoil}\right) gff_n}{gff_{tot}} \tag{3.256}$$

$FC^{leak}_{environ}$ = (0*5000 +185.48*1500)*2e-6/(7e-4)

$FC^{leak}_{environ}$ = 278220

STEP 12.7 – Determine the total barrels of fluid released by a tank bottom rupture, $_{ruptura\ release}Bbl$.

$$Bbl^{rupture}_{release} = \frac{Bbl_{total} \cdot gff_4}{gff_{tot}} \tag{3.257}$$

$Bbl^{rupture}_{release}$ = 185.75 * 2e-6/7.2e-4 = 0.5159

STEP 12.8 – Compute the total barrels of fluid within the dike from a rupture, $Bbl^{rupture}_{indike}$, the total barrels of fluid in the on-site surface soil, $Bbl^{rupture}_{ss-onsite}$, the total barrels of fluid in the off-site surface soil, $Bbl^{rupture}_{ss-offsite}$, and the total barrels of fluid that reach water, $Bbl^{rupture}_{water}$, using Equations (3.245) through (3.248), respectively.

$$Bbl_{indike}^{rupture} = Bbl_{release}^{rupture}\left(1-\frac{P_{lvdike}}{100}\right) \quad (3.245)$$

$$Bbl_{ss-onsite}^{rupture} = \frac{P_{onsite}}{100}\left(Bbl_{release}^{rupture} - Bbl_{indike}^{rupture}\right) \quad (3.246)$$

$$Bbl_{ss-offsite}^{rupture} = \frac{P_{offsite}}{100}\left(Bbl_{release}^{rupture} - Bbl_{indike}^{rupture} - Bbl_{ss-onsite}^{rupture}\right) \quad (3.247)$$

$$Bbl_{water}^{rupture} = Bbl_{release}^{rupture} - \left(Bbl_{indike}^{rupture} + Bbl_{ss-onsite}^{rupture} + Bbl_{ss-offsite}^{rupture}\right) \quad (3.248)$$

Bblruptureindike = 0.5159 * (1-0.3) = 0.3611
Bblrupturessonsite = 50/100*(0.51559-0.3611) = 0.0773
Bblrupturessoffsite = 20/100*(0.51559-0.3611-0.0733) = 0.01544
Bblrupturewater = 0.5159 * (0.3611 + 0.0733 + 0.01544) = 0.0619

STEP 12.9 – Compute the financial environmental cost for a tank bottom rupture, $FC_{environ}^{rupture}$, using Equation (3.249) where $Bbl_{indike}^{rupture}$, $Bbl_{ss-onsite}^{rupture}$, $Bbl_{ss-offsite}^{rupture}$, and $Bbl_{water}^{rupture}$ are from STEP 12.8.

$$FC_{environ}^{rupture} = Bbl_{indike}^{rupture} \cdot C_{indike} + Bbl_{ss-onsite}^{rupture} \cdot C_{ss-onite} + Bbl_{ss-offsite}^{rupture} \cdot C_{ss-offite} + Bbl_{water}^{rupture} \cdot C_{water} \quad (3.249)$$

$FC_{environ}^{rupture}$ = 0.3611*10+0.0773*50+0.01544*250+0.0619*1500

$FC_{environ}^{rupture}$ = 104.27

STEP 12.10 – Compute the total financial environmental cost from a leak and a rupture, $FC_{environ}$, using Equation (3.250) where $FC_{environ}^{leak}$ is from STEP 12.6 and $FC_{environ}^{rupture}$ is from STEP 12.8.

$FC_{environ} = FC_{environ}^{leak} + FC_{environ}^{rupture}$ = 4517382.6 + 104.27 =$278324.28

STEP 12.11 – Compute the component damage cost, FC_{cmd}, using Equation (3.258) with the release hole size damage costs from Table 5.15 and generic failure frequencies for the release hole sizes from

Table 5.15 – Component Damage Costs

Equipment Type	Component Type	Damage Cost (2001 US Dollars), *holecost*			
		Small	Medium	Large	Rupture
Compressor	COMPC	10000	20000	100000	300000
Compressor	COMPR	5000	10000	50000	100000
Tank650	TANKBOTTOM	5000	0	0	120000
[illegible]	[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Holecostn = 5000
Holecost4 = 120000
C36 = 30.5
Gffsmall = 2e-6
gfftotal = 7.2e-4

Table 5.16 – Material Cost Factors

Material	Cost Factor, *matcost*	Material
Carbon Steel	1.0	90/10 Cu/Ni

matcost = 1

$$FC_{cmd} = \left(\frac{\sum_{n=1}^{3} gff_n \cdot holecost_n + holecost_4 \left(\frac{D_{tank}}{C_{36}} \right)^2}{gff_{total}} \right) \cdot matcost \tag{3.258}$$

FC_{cmd} = (7.2e10-4*5000+120000*(10.7/30.5)*(10.7/30.5)/7.2e10-4*1

FC_{cmd} = $20517407.1

<u>STEP 12.12 – For each release hole size, calculate the cost of business interruption due to the outage days required to repair the damage to equipment.</u>

1) Calculate the downtime required to repair the specific piece of equipment using Equation (3.100) and the downtime for each release hole size, ${}_{n}Outage$, from Table 5.17.

$$Outage_{cmd} = \left(\frac{\sum_{n=1}^{4} gff_n \cdot Outage_n}{gff_{total}} \right) \cdot Outage_{mult}$$

Outagecmd = 5.1388days

Table 5.17 – Estimated Equipment Outage

Equipment Type	Component Type	Estimated Outage in Days, $Outage_n$			
		Small	Medium	Large	Rupture
Compressor	COMPC	2	3	7	14
Compressor	COMPR	2	3	7	14
Pump	PUMP1S	0	0	0	0
Tank650	TANKBOTTOM	5	0	0	50
Tank650	COURSE-1	[illegible]	[illegible]	[illegible]	[illegible]

An outage multiplier, $Outage_{mult}$, is used to adjust downtimes expected for extreme delivery situations. For this example, $Outage_{mult}$ is 1.

2) Calculate the cost of business interruption, FC_{prod}, using Equation (3.102). The production costs, $prodcost$, is the cost of loss production on the unit, $/day. Note that in this calculation, the downtime required to repair the surrounding equipment in the affected area, $Outage_{affa}$, is assumed to be zero.

$$FC_{prod} = \left(Outage_{cmd} + Outage_{affa}\right)\left(prodcost\right) \qquad (3.102)$$

Prodcost =$50000/day

FC_{prod} = $256944.44

STEP 12.13 – Calculate the total financial consequence using Equation (3.259).

$$FC_{total} = FC_{environ} + FC_{cmd} + FC_{prod}$$

FC_{total} = 4517486.88 + 20517407 + 256944.44 = $25286838.4

This value is a #5 Consequence Category