Wind and Earthquake Loads On The Analysis of a Vertical Pressure Vessel For Oil Separator

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ABSTRACT

Mechanical analysis of a three phase oil separator had been done previously without wind and earthquake load yet. Therefore this research is focused on the mechanical analysis that takes into account the wind and earthquake loads. The mechanical analysis follows ASME Code Section VIII and was conducted using graphical based software. Since ASME standard code does not provide specifically construction code on wind and earthquake load then it follows the standard of ASCE 7-2005 for wind load and ASCE 7-98/02/ IBC 2000 for earthquake load. Wind load was determined base on wind speed pressure, gust-effect factor, force coefficient and projected area normal to the wind. Earthquake load depends on intensity and duration of earthquake. Analysis was carried out on the head, shell, nozzle and skirt of the vessel though wind and earthquake load effect the skirt only. The objectives of this research are to determine the vibration possibility and static deflection due to the wind load and allowable stress due to earthquake load on the vessel design. The result shows that the pressure vessel in a stable condition and the static deflection is less than the allowable deflection. The pressure vessel also meets the criteria of stress due to earthquake load.

Keywords : Oil separator, pressure vessel, wind load, earthquake load, graphical-based software.

1. INTRODUCTION

Oil separators are constructed in diverse design e.g. horizontal, vertical or spherical. Vertical separator is mainly used in the area with limitation of space. This paper expressed the design of vertical three phase separator that normally illustrated as in Figure 1[1]. The three phase separator separates liquid into oil/emulsion, gas, and water. Gas comes out from the top, oil/emulsion from the middle, and water from the bottom. Process design of three phase separator that follows API standard and discussion on mathematical model and thermodynamic analysis had been done [2,3]. Implementation of Ansys software for design and analysis static loading on pressure vessel has also been studied [4]. The main result is to check the behavior of pressure vessel under fluctuating load include various aspects such as selecting the material based on ASME codes. Others studies on the topic of mechanical design of pressure vessel employed manual calculation and implementation of software. Most of them of discussed the internal and external pressure, weight of the elements and allowable stress on each component [5,6]. The load design of the pressure vessel can be classified into two types those are major and subsidiary load. Major load are load due to pressure design, maximum weight of the pressure vessel and its contents under operating conditions, maximum weight of the pressure vessel and its contents under the hydraulic test conditions, wind, earthquake and supporting payload of the pressure vessel. Subsidiary loads are due to local stress which is caused by the support, the internal structure and the connector pipe, shock loads which is caused central eccentricity of the relative pressure toward the neutral axis of the pressure vessel, stress due to the temperature and expansion coefficients of the materials differences and loads caused by fluctuations in temperature and pressure. Wind and earthquake load as major loads that affect the pressure vessel design have been hardly considered. Therefore this research would deliberate wind and earthquake load on the design of vertical three phase oil separator which is basically a pressure vessel, using graphical-based software.

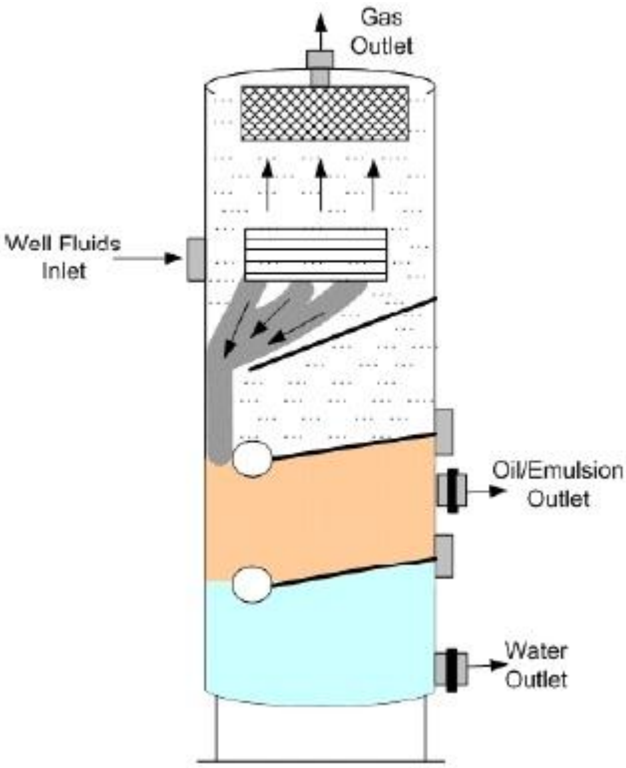

Figure 1. Vertical Three-Phase Oil Separator

2. RESEARCH METHOD

The specification of vertical three phase oil separator was attained from a pressure vessel manufacture [7]. The mechanical analysis follows ASME Code Section VIII and was conducted using graphical based software. The separator was drawn simply using suitable icon. Design parameter for each by water, or by the surge of the pressure vessel contents, elastic moment due to the component i.e. skirt, head, shell, nozzle was entered on the input screen by clicking the component. Design parameter would be as the following: shell diameter, length, thickness, design pressure, design temperature, allowable maximum corrosion and type of material. Design procedure and equations follows ASME Code Section VIII. Since ASME standard code does not provide specifically construction code on wind and earthquake load then it follows the standard of ASCE 7-2005 for wind load and ASCE 7-98/02/ IBC 2000 Earthquake Parameters for earthquake load. Wind load was calculated using equation 1.

$$F = q_z\, G\, C_f A_f \text{ (N)}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where
q_z = wind speed pressure (N/m^2)
G = gust-effect factor
Cf = force coefficient
Af = projected area normal to the wind (m^2)

Wind speed pressure is a pressure that evaluated at an altitude of z and distribution of wind speed pressure (q_z) is determined using equation 2 [8].

$$q_z = 0.613\, K_z\, K_{zt}\, K_d\, V^2\, I\, (N/m^2). \quad \ldots\ldots\ldots \text{(2)}$$

Where :
V = wind velocity (m/s)
K_z = velocity pressure exposure coefficient
K_{zt} = topographic factor
K_d = wind directionality factor
I = importance factor

Velocity pressure coefficient, K_z is determined based on height of location, exposure category and terrain exposure. Topographic factor, K_{zt}, is determined based on condition specified in ASCE 7. If the site conditions and the location of the structure did not meet all the conditions specified in ASCE 7 then Kzt equal 1.0 can be chosen [9]. Wind directionality factor, K_d is depend on the type of structure and vertical pressure vessel can be considered as a pile therefore the wind directionality factor is 1.0.

Gust Effect Factor (G)

The influence gust factor, G, is probably the most important parameter to calculate, and the result is almost always the same within the range predicted. The standard of ASCE 7, (2005) [8] defines a rigid structure is a structure that experiences a fundamental natural frequency which is equal to or greater than 1 Hz. For rigid structure, G is 0.85. In this case, the algorithm must be done very long to get G. Usually, G is rarely less than 1.4. For quick estimation the value of G that is 1.5 will handle most of the cases [9].

Earthquake Load Design

Vibration of the earth surface during an earthquake generates a horizontal shear force at height of tank. The magnitude of shear force will increase from the bottom of pressure vessel to the top pressure vessel. A major factor of structure deterioration is the intensity and the duration of earthquake vibration. Force and stress in the structure during the earthquake is temporary, dynamic due to nature, and complex [9].

Some of the following information is needed to consider the effect of the earthquake on the pressure vessel:

- Seismic zone.
- The height or length and thickness of the pressure vessel shell.
- Support system type
- Site of the coefficient that is a function of soil types.
- Vessel's weight operation (both pre-service and in-service).
- The location.

ASCE 7-98/02/ IBC 2000 Earthquake Parameters

a. Earthquake Parameters Ss and Sl

The values for Ss and Sl are taken from the standard of ASCE 7-98 / IBC 2000 / 2003.

For for short term, the factor is 0,2 for long terms is 1.0.

b. Response Modification Factor R

R usually equals to 2.5 for inverted pendulum and cantilever column system. For high tanks, the value is 4 and for horizontal vessel, supported legs vessel and others the value is 3.

c. Importance Factor

Importance factor usually in the range of 1.0 and 1.5

d. Moment Reduction Factor, Tau

This value is used to reduce moment at any rate. Moment reduction factor greater than one will increase the moment, while less than one will reduce moment. Value 1 is suggested [10].

e. Earthquake parameters Fa and Fy shown in Tables 1 and Table 2.

Table 1. Earthquake parameters Fa

Site Class	Mapped MCE Short Period Spectral Response Acceleration Parameter (Linear Interpolation Is Permitted)				
	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	These values to be determined by site response analysis.				

Table 2. Earthquake parameters Fy

Site Class	Mapped MCE Long Period Spectral Response Acceleration Parameter (Linear Interpolation Is Permitted)				
	$S_1 \le 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 \ge 0.50$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	These values to be determined by site response analysis.				

f. Component Elevation ratio, z/h

If the pressure vessel attach to another structure such as building, the elevation ratio value needs to be put for precise analysis.

Illustration of elevation ratio is shown in Figure 2. This ratio is high in a structure where the pressure vessel attaches to average height. So, in general, the value will always less than or equal to 1[10].

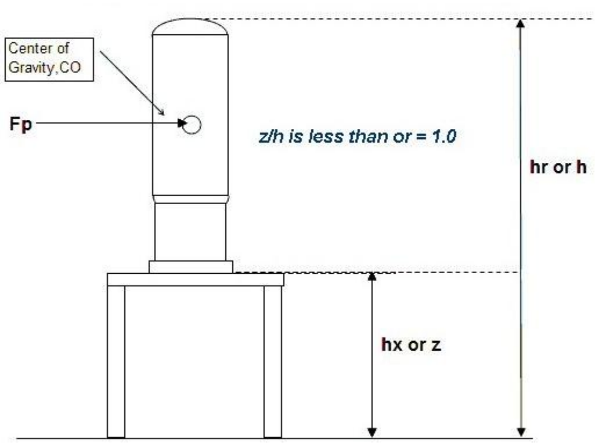

Figure 2. Component Elevation ratio, z/h[10]

Site Class (Soil Type)

Site class is related with soil and rock types which are directly underlying a building. The range of site class from A-F is to go forward from stiffest to softest. Table 3 shows a list of the various site classes which are related. Class site is determined in accordance with the reference stated above from ASCE 7-98/02 and ASCE 7-05[10].

Table 3. Site Class- Soil Type[10]

Site Class	Soil Type
A	Hard Rock
B	Rock
C	Very Dense Soil & Soft Rock
D	Stiff Soil (Default Site Class)
E	Soft Clay Soil
F	Liquefiable Soils, Quick Highly Sensitive Clays, Collapsible Weakly Cemented Soils, & etc. These require site response analysis.

Mapped Acceleration Parameter

Mapped Acceleration parameter is available in ASCE 7-98/02 for 2000/2003 IBC and ASCE 7-05 for year 2006 IBC, or can be obtained from USGS catalogs by ZIP code. Mapped short period acceleration parameter is usually denoted as SS and mapped long period acceleration parameter is denoted as S1. Note that the values for SS and S1 may different from 2000/2003 and IBC 2006. Make sure the correct values which are used for code which is valid in an input data [10].

Then, these site class information are used to determine the spectral acceleration design parameter, SDS and SD1, for short and long period of each MCE. The technique to estimate the spectral acceleration parameter design is shown in equations 3 and 4.

$$SDS = 2/3\ Fa\ SS. \quad \text{(3)}$$

$$SD1 = 2/3\ Fv\ S1. \quad \text{(4)}$$

Where:

Fa = The Short Period Site Coefficient which is listed in table 3, The values for Fa which corresponds to values of SS are listed in Table 4 can be obtained through linear interpolation.

Fv = Long Period Coefficient Site is listed in table 3, the value for Fv which is in accordance with the values of S1 which is listed in table 5 can be obtained through linear interpolation.

SDS = Short Period Spectral Response Acceleration Parameter which has been corrected for the class site.
SD1 = Long Period Spectral Response Acceleration Parameter which has been corrected for the class site.
SS = Mapped Short Period Acceleration Parameter for @ MCE 5% damping.
S1 = Mapped Long Period Acceleration Parameter for @ MCE 5% damping.

Table 4. Short Period Site Coefficient, Fa[10]

Site Class	Mapped MCE Short Period Spectral Response Acceleration Parameter (Linear Interpolation Is Permitted)				
	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	These values to be determined by site response analysis.				

Table 5. Long Period Site Coefficient, Fv[10]

Site Class	Mapped MCE Long Period Spectral Response Acceleration Parameter (Linear Interpolation Is Permitted)				
	$S_1 \le 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 \ge 0.50$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	These values to be determined by site response analysis.				

Table 6. Seismic Design Category, S_{DS} [10]

Value of S_{DS}	Occupancy Category (Seismic Use Group)		
	I or II (I)	III (II)	IV (III)
$S_{DS} < 0.167$	A	A	A
$0.167 \le S_{DS} < 0.33$	B	B	C
$0.33 \le S_{DS} < 0.50$	C	C	D
$0.50 \le S_{DS}$	D	D	D

Stability of the wind load design

Vibration possibility was investigated based on wind load design as on equation 5, 6. Static deflection was compare to allowable deflection.

$V_p = W/LD_r^2$. ……………………………….......... (5)

Where: V_p is vibration possibility, if $V_p > 25$ then vibration occured.

$V_c = 3.4\ D/T$. ………………….............. (6)

Where : V_c is critical wind speed , if $V_c >$ 22.3515 then the pressure vessel is stable.

$$\Delta d = \frac{(2.43)(10^{-9})(L^5)(V_c{}^2)}{W\delta Dr} \quad (7)$$

Where Δd: Static deflection if, $\Delta d < 6$ in or 100 ft or in SI unit : $\Delta d < 0.1524$ m then design is accepted because it is less than the allowable deflection.

3. RESULT AND DISCUSSION

The result of wind load analysis on the pressure vessel can be generated directly from the software and it can be save in the form of report or table as it is presented in Table 7, Table 8 and Table 9.

Wind Analysis Results :
User Entered Importance Factor is : 1.000
Gust Effect Factor (Ope)(G or Gf) Dynamic : 0.889
User entered Beta Value (Operating Case) : 0.0100
Shape Factor (Cf) : 0.617
User Entered Basic Wind Speed : 11.2 m/sec
Sample Calculation for the First Element
Value of [Alpha] and [Zg]
Exposure Category = 3 (C) thus from Table C6-2:
Alpha = 9.500 : Zg = 274.320 m
Effective Height [z]
= Centroid Hgt. + Vessel Base Elevation
= 0.657 + 0.000 = 0.657 m
= 2.156 ft. Imperial Units
Compute [Kz]
Because z (2.156 ft.) < 15 ft.
= 2.01 * (15 / Zg) $^{2 / \text{Alpha}}$
= 2.01 * (15 / 900.000)$^{2 / 9.500}$
= 0.849

Type of Hill: No Hill
Directionality Factor for round structures [Kd]:

= 0.95 per [6-6 ASCE-7 98][6-4 ASCE-7 02/05]

As there is No Hill Present: [Kzt]
K1 = 0, K2 = 0, K3 = 0
Topographical Factor [Kzt]
= (1 + K1 * K2 * K3)²
= (1 + 0.000 * 0.000 * 0.000)²
= 1.0000
Basic Wind Pressure, Imperial Units [qz]:
= 0.00256 * Kz * Kzt * Kd * I * Vr(mph)²
= 0.00256 * 0.849 * 1.000 * 0.950 * 1.000 * (25.054)²
= 1.296 psf [0.062] kPa

Force on the first element [F]:
= qz * Gh * Cf * WindArea
= 0.062 * 0.889 * 0.617 * 5.007
= 170.221 N

Table 7. Element Data Pressure Vessel Oil Separator by Wind Load Calculation

Element	Hgt (z) m	K1	K2	K3	Kz	Kzt	qz kPa
Skirt	0.7	0.000	0.000	0.000	0.849	1.000	0.062
Bottom Head	2.5	0.000	0.000	0.000	0.849	1.000	0.062
shell 1	4.8	0.000	0.000	0.000	0.856	1.000	0.063
Node 40 to 50	6.0	0.000	0.000	0.000	0.889	1.000	0.066
Shell 2	7.3	0.000	0.000	0.000	0.935	1.000	0.068
Shell 3	9.8	0.000	0.000	0.000	0.996	1.000	0.073
Shell 4	12.3	0.000	0.000	0.000	1.045	1.000	0.076
Top Head	14.9	0.000	0.000	0.000	1.089	1.000	0.080

Table 8. Wind Load Calculation

From To	Wind Height m	Wind Diameter m	Wind Area m²	Height Factor kPa	Element Wind Load N
10 to 20	0.65707	3.33864	5.00672	0.062047	170.221
20 to 30	2.50000	2.14848	5.3721	0.062047	182.662
30 to 40	4.75000	2.14848	5.36987	0.062548	184.041
40 to 50	6.00150	2.14848	5.3721	0.065704	194.447
50 to 60	7.25300	2.14848	5.36987	0.068377	400.447
60 to 70	9.75300	2.14848	5.36987	0.072776	422.748
70 to 80	12.2530	2.14848	5.36987	0.076358	427.713
80 to 90	14.9419	2.14848	6.17305	0.079615	490.346

The result of earthquake load on the pressure vessel can also display similarly with the wind load analysis. Report were generated includes the equations that had been used to find the result. Moreover the results were also presented in Table 10 and Table 11.

Table 9. Wind Shear Bending

From	To	Distance to Support m	Cummulative Wind Shear N	Earthquake Shear N	Wind Bending N-m	Earthquake Bending N-m
10	20	0.75000	2241.80	0.00000	20971.9	0.00000
20	30	2.50000	2071.58	0.00000	17735.5	0.00000
30	40	4.75000	1925.53	0.00000	13736.8	0.00000
40	50	6.00150	1741.49	0.00000	9151.17	0.00000
50	60	7.25300	1741.25	0.00000	9145.94	0.00000
60	70	9.75300	1340.81	0.00000	5291.80	0.00000
70	80	12.2530	918.059	0.00000	2467.08	0.00000
80	90	14.7530	490.346	0.00000	705.858	0.00000

Earthquake Analysis Results per ASCE 7-98 :
User Entered Table Value 9.4.1.2.4a
Fa 1.000
User Entered Table Value 9.4.1.2.4b
Fv 1.400
Max. Mapped Acceleration Value for Short Periods Ss 1.00
Max. Mapped Acceleration Value for 1 sec. Period S1 0.400
Moment Reduction Factor
Tau 1.000
Force Modification Factor
R 3.000
Importance Factor
I 1.000
Site Class
C
Sms = Fa * Ss = 1.000 * 1.000 = 1.000
Sm1 = Fv * S1 = 1.400 * 0.400 = 0.560
Sds = 2/3 * Sms = 2/3 * 1.000 = 0.667
Sd1 = 2/3 * Sm1 = 2/3 * 0.560 = 0.373

Check the Period (1/Frequency) from 9.5.3.3-1 = Ct * hn3/4 where Ct = 0.020 and hn = total Vessel Height [Ta]:
= 0.020 * 16.42213/4 = 0.398 seconds

The Coefficient Cu from Table 9.5.3.3 is 1.300
Check the Min. Value of T which is the Smaller of Cu*Ta and T, [T]:
= Min. Value of (1.300 * 0.398 , 1/6.699) = 0.1493 per 9.5.3.3
Compute the Seismic Response Coefficient Cs per 9.5.3.2.1, [Cs]:
= Sds / (R / I)
= 0.667 / (3.00 / 1.00) = 0.2222
Check the Maximum value of Cs per eqn. 9.5.3.2.1-2 :
= Sd1 / ((R / I) * T)
= 0.373 / ((3.00 / 1.00) * 0.149) = 0.8336

Check the Minimum value of Cs per eqn. 9.5.3.2.1-3:
= 0.044 * 1.00 * 0.667 = 0.0293

Compute the Total Base Shear V = Cs * Total Weight, [V]:
= 0.2222 * 474627.4 = 105472.76 N
The Natural Frequency for the Vessel (Ope...) is 6.69895 Hz.

Table 10. Earthquake Load Calculation

From To	Earthquake Height m	Earthquake Weight N	Element Ope Load N	Element Emp Load N
10 to 20	0.75000	79343.8	1240.36	1240.36
20 to 30	2.50000	63433.1	3305.44	3305.44
30 to 40	4.75000	61299.0	6069.03	6069.03
40 to 50	6.00150	71.5311	8.94803	8.94803
50 to 60	7.25300	63938.2	9666.08	9666.08
60 to 70	9.75300	63711.9	12951.8	12951.8
70 to 80	12.2530	63938.2	16329.6	16329.6
80 to 90	14.7530	78891.8	24259.7	24259.7

However for bending calculation could not been done simultaneously. Whenever wind load analysis was carried out then earthquake load was considered to be zero.

Table 11. Earthquake Shear, Bending

From	To	Distance to Support m	Cummulative Wind Shear N	Earthquake Shear N	Wind Bending N-m	Earthquake Bending N-m
10	20	0.75000	0.00000	73830.9	0.00000	797398.
20	30	2.50000	0.00000	72590.6	0.00000	687538.
30	40	4.75000	0.00000	69285.1	0.00000	545604.
40	50	6.00150	0.00000	63216.1	0.00000	379911.
50	60	7.25300	0.00000	63207.2	0.00000	379721.
60	70	9.75300	0.00000	53541.1	0.00000	233727.
70	80	12.2530	0.00000	40589.2	0.00000	116016.
80	90	14.7530	0.00000	24259.7	0.00000	34922.1

Stability of the wind load design presented in vibration possibility and critical wind speed criteria. Based on equation 5 then the vibration possibility is

W/LD_r^2 = 453206 / (16.00 * 1.683²)
= 0.10005E+05
which is much less than 25.

Critical wind speed is determined using Equation 6 and the result is 38.4 m/s, which is greater than 22.3 m/s. The pressure vessel design is in a stable state.

The static deflection of the wind load is calculated based on equation 7 and the result is 0.00116 m which is less than 0.1524 m.

Stress due to earthquake load studied in three different parameter i.e. primary stress, primary general stress, and primary membrane local stress that would be compared to maximum allowable stress on the material. This calculation had been studied in many report of pressure vessel design however the load were merely the design load that had not considered earthquake load [4,5,6,10,11].

Maximum allowable stress on the material SA 516 70 with design metal temperature 150^o F from Table code UG 23 is 120.65 N/mm^2. The oil separator design fulfills the standard of earthquake load as the allowable stress design i.e. primary stress, primary general stress, and primary membrane local stress is less than the maximum allowable stress of the material.

4. CONCLUSSION

The wind and earthquake loads on the analysis of the oil separator design have been performed applying graphical-based software. The results could be presented rapidly in the form of file report included the equations and table. Maximum bending moment which occurred in the oil separator design is 20971.9 N-m. Based on the vibration possibility and static deflection due to the wind load and allowable stress due to earthquake load, it was found that the pressure vessel design in a stable condition and the static deflection is less than the allowable deflection. The pressure vessel also meets the criteria of stress due to earthquake load.

Simultaneous load involved all direction of load is necessary to be done in the future. Moreover dynamic analysis and real time simulation are a very constructive research in the topic of pressure vessel design.

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