This is MecaStack Output corresponding to Numerical Example No. 1 in Troitsky.

Breach # 1: Elev 10.00 ft, Load # 8
Load Combination # 8, D+W 0 Deg

Controlling: Vertical Stiffener, Circumferential Stiffener, Shell Buckling Capacity w/ Breach

Breach Analyis based upon 'Tubular Steel Structures' by M.S. Troitsky
Analysis assumes that this is the only breach and doesn't consider interaction with other openings.

```
Elev      = Elevation Where Breach Ctr Line Intersects Stack Ctr Line       = 10.000 ft

ElTop     = Elevation at Top of Breach                                      = 14.000 ft
ElBot     = Elevation at Bottom of Breach                                   = 6.000 ft
Wid       = Width of Breach Opening                                         = 60.0000 in
Ht        = Height of Breach Opening                                        = 96.0000 in
Tilt      = Tilt of Duct relative to grade (0 is Horizontal)                = 0.0 Deg
OD        = Outer Diameter at Elevation                                     = 186.0000 in
Thk       = Thickness of Stack                                              = 0.5000 in

Loads Acting @ Breach (Take worst of loads at Top, Mid and Bot of Breach):
V         = Vertical Load                                                   = 114.77 Kip
M         = Moment due to Lateral Loads                                     = 2097.69 k-ft

Yc        = Distance from Centerline to Elastic Neutral Axis                = 26.8174 in
r         = Radius to Outside of Stack                                      = 93.0000 in
r1        = Radius to Inside of Stack                                       = 92.5000 in
Dm        = Mean Diameter:  2*(r+r1)/2                                      = 185.5000 in
Alpha     = Half Angle of Opening:  ArcSin(Wid/OD)                          = 0.3285 rads
Beta      = Angle to Neutral Axis:  ArcSin(Yc/r)                            = 0.2925 rads
Gamma1    = (PI/2 - Alpha + Beta)/2                                         = 0.7674 rads
Gamma2    = (PI/2 - Alpha - Beta)/2                                         = 0.4749 rads
Sc        = Statical Moment Under Compression                               = 9279.80 in^3
St        = Statical Moment Under Tension                                   = 5057.68 in^3
Ic        = Moment of Inertia of Wall Under Compression                     = 775699.22 in^4
It        = Moment of Inertia of Wall Under Tension                         = 263587.55 in^4
Phi       = (Mom + Ver*Yc) / (Ic + It)                                      = 27.1821
N         = Phi * (Sc-St)                                                   = 114.77 Kip
```

Breach # 1 Ld 8 Cylinder Buckling Capacity:

This checks the reduced buckling capacity for the cylinder considering that it is weakened by the breach cutout. Reduction is based upon Troitsky Fig 5-23 for Effect of Rect Cutout on Cylindrical Buckling Capacity.

```
fclassic  = Classic Buckling Stress for Cylinder: 0.6*E*t/r                 = 90.65 ksi
FS        = Factor of Safety for Compression                                = 0.600
rbar      = Non-dimensional parameter: (Wid+Ht) / (4*((OD/2)*Thk)^0.5)      = 5.719
P/Pcl     = Actual / Classical Buckling Capacity {Fig 5-23}; Max = 0.2      = 0.186
fmax      = Max Comp Stress: (Phi/2)*(2*Yc+(r+r1)*COS(Alpha))               = 3.12 ksi
fallow    = Allowable Reduced Buckling Stress: (P/Pcl)*fclassic*FS          = 10.10 ksi
UR_sb     = Shell Buckling Unity Ratio: fmax/fallow                         = 0.309
```

This check indicates that even with the breach the shell still has enough capacity to resist the applied loads. Since vertical stiffeners were provided anyway, those will be checked using the selected criteria as if the shell was failing with Fac = 1.

```
Ver Stiff (one on each side of opening):
Country   = Country Dimensions for Shape                                    = American
Shape     = IBeam Strong Direction                                          = IBEAM
Size      = Size of Structural Member                                       = W10X54
Matl      = Material of Stiffener                                           = A-36
Temp      = Temperature considered for Material Properties                  = 70.00 Deg F
Fy        = Yield Stress of Stiffener @ Temp                                = 36.00 ksi
E         = Modulus of Elasticity of Stiffener @ Temp                       = 29400.00 ksi
Dv        = Distance from Opening Edge to Edge of Stiffener                 = 3.0000 in
Dva       = Distance from Opening Edge to Top of Stiff Above Opening        = 3.0000 in
Dvb       = Distance from Opening Edge to Top of Stiff Below Opening        = 3.0000 in
Dca       = Dist from Opening Edge to Circ Stiffener Above Opening          = 3.0000 in
Dcb       = Dist from Opening Edge to Circ Stiffener Below Opening          = 3.0000 in
```

Breach # 1 Ld 8 Ver Stiff: Complete Breach Area Replacement:

```
HA        = Half Angle of Breach Opening                                    = 18.82 Deg
                                                                            = 0.3285 rads
Ycent     = Dist from OD to Stiff Centroid: D/2                             = 5.0500 in
ds        = Dist from Ctr Line to Ctr of Ver Stiff: (OD/2+Ycent)*Cos(HA)    = 92.8084 in
As_reqd   = Req'd Area of a Single Stiffener: Thk*(OD/2)^2*Sin(HA)/ds       = 15.031 sq in
Aratio    = Ratio of Required to Actual Area: As_reqd/A                     = 0.951
```

Breach # 1 Ld 8 Ver Stiff: Complete Breach Moment of Inertia Replacement:

```
Iv_rot    = Rotated Mom of Inertia of Stiff: Ix*Sin(HA)^2+Iy*Cos(HA)^2      = 123.81 in^4
Irem      = Mom of Inertia of Removed Sec: r^3*(HA+Sin(2*HA)/2)*Thk         = 254897.01 in^4
Ireq      = Req'd Mom of Inertia of Stiff about Stack Ctr Line: Irem/2      = 127448.50 in^4
Iv_tot    = Act Mom of Inertia of Stiff about Stack Ctr Line: Iv_Rot+A*ds^2 = 136215.64 in^4
Iratio    = Ratio of Required to Actual Mom of Inertia:  Ireq/Iv_tot        = 0.936
```

Breach # 1 Ld 8 Ver Stiff: Determine Axial Load and Bending on a Stiffener:

```
G         = Axial Load Due to Stack Vertical Load: V*Alpha/(2*PI)           = 6.00 Kip
Pw        = Axial Load Due to Moment: M*Alpha/(0.5*PI*Dm)                   = 28.37 Kip
Pr        = Total Axial Load on Stiffener: G+Pw                             = 34.37 Kip
dv        = Depth of Vertical Stiffener Radially from Shell                 = 10.1000 in
Lv        = Effective Stiff Length:  Ht+Dca+Dcb                             = 102.0000 in
Mry       = Moment Due to Eccentricity: Pr*(dv/2)                           = 173.59 K-in

Ver Stiff: Member properties taken from AISC 360-16
Country   = Country Database for Member Dimensions                          = American
Shape     = IBeam Strong Direction                                          = IBEAM
Size      = Size of Member                                                  = W10X54
Ag        = Cross Sectional Area                                            = 15.800 sq in
Ix        = Moment of Inertia about X                                       = 303.00 in^4
Iy        = Moment of Inertia about Y                                       = 103.00 in^4
Imaj      = Principal Major Moment of Inertia                               = 303.00 in^4
Imin      = Principal Minor Moment of Inertia                               = 103.00 in^4
J         = Torsional Constant                                              = 1.82 in^4
Sx        = Elastic Sec Modulus about X                                     = 60.00 in^3
Sy        = Elastic Sec Modulus about Y                                     = 20.60 in^3
Zx        = Plastic Sec Modulus about X                                     = 66.60 in^3
Zy        = Plastic Sec Modulus about Y                                     = 31.30 in^3
Xc        = Distance in X to Centroid                                       = 0.0000 in
Yc        = Distance in Y to Centroid                                       = 0.0000 in
rx        = Radius of Gyration about X                                      = 4.3700 in
ry        = Radius of Gyration about Y                                      = 2.5600 in

Ver Stiff: Nominal Compressive Strength per AISC 360-16 Sec E3:
Lc        = Effective Length of Member                                      = 102.0000 in
r         = Minimum of Radius of gyration:  Min(rx, ry)                     = 2.5600 in
Lc/r      = Slenderness Ratio                                               = 39.844
Limit     = Limit used for Lc/r:  4.71*(E/Fy)^0.5                           = 134.599
Fe        = Elastic Buckling Stress:  PI^2*E / (Lc/r)^2   {E3-4}            = 182.78 ksi
Limit     = Limit used for Lc/r:  4.71*(E/Fy)^0.5                           = 134.599
Fcr       = Critical Stress: [0.658^(Fy/Fe)]*Fy   {E3-2}                    = 33.15 ksi
Pn_fb     = Flexural Buckling Strength:  Fcr*Ag {E3-1}                      = 523.79 Kip

Ver Stiff: Nominal Compressive Strength per AISC 360-16 Sec E4:
Lcx       = Effective Length of Member about X-Axis                         = 102.0000 in
Lcy       = Effective Length of Member about Y-Axis                         = 102.0000 in
Lcz       = Effective Length of Member about Z-Axis                         = 102.0000 in
ho        = Dist between flange Centroids:  D-Tf                            = 9.4850 in
Cw        = Warping Constant: From AISC                                     = 2320
G         = Shear Modulus of Elasticity of Steel                            = 11200.00 ksi
Fe        = (PI^2 *E*Cw/Lcz^2 + G*J) * (1/(Ix+Iy))  {E4-2}                  = 209.58 ksi
Fcr       = Critical Stress: [0.658^(Fy/Fe)]*Fy   {E3-2}                    = 33.50 ksi
Pn_FTB    = Flexural Torsional Buckling Strength: Fcr*Ag {E4-1}             = 529.34 Kip

Ver Stiff: Nominal Compressive Strength per AISC 360-16 E3 & E4:
Pn        = Lessor of Pn_fb or Pn_ftb                                       = 523.79 Kip
Pc        = Design Compressive Strength: Pn/1.67 (ASD)                      = 313.65 Kip

Ver Stiff: Nominal Flexural Strength per AISC 360-16 Sec F6: (Weak Axis)
Mp        = Plastic Moment:  Fy*Zy <= 1.6*Fy*Sy {F6-1}                      = 1126.80 K-in
Mn_y      = Yielding Nominal Flexural Strength:  Mp {F6-1}                  = 1126.80 K-in
Flexure Flange Classification Table B4.1b:
Lambda    = Compact criteria taken from AISC 360-16: Bf/2Tf                 = 8.150
Lambda_p  = Limiting Width-to-Thk Ratio from Table B4.1b: 0.38*(E/Fy)^0.5   = 10.859
Lambda_r  = Limiting Width-to-Thk Ratio from Table B4.1b: 1.00*(E/Fy)^0.5   = 28.577
FS        = Flange Slenderness: Since Lambda <= Lambda_p                    = Compact
Since Flanges are compact the Flange Local Buckling criteria doesn't apply
Mn        = Lessor of Mn_y and Mn_flb                                       = 1126.80 K-in
Mcy       = Design Flexural Strength for ASD:  Mn / 1.67 {F1}               = 674.73 K-in

Ver Stiff: Check Member for Combined Flexure and Axial per Sec. H1-1:
Pr        = Required Axial Strength (+ is Compression)                      = 34.37 Kip
Mrx       = Required Flexural Strength about Strong Axis                    = 0.00 K-in
Mry       = Required Flexural Strength about Weak Axis                      = 173.59 K-in
Pr/Pc     = Ratio of Required to Available Axial Strength                   = 0.1096
Since Pr/Pc < 0.2 then use Eqn H1-1b
H1-1b     = Pr/(2*Pc)+(Mrx/Mcx+Mry/Mcy)  {H1-1b}                            = 0.312
```

The section properties for the stack have been modified in the breach region to consider the addition of the vertical stiffeners. The stack stresses and dynamic behavior will all take these modified section properties into account in those analyses.

UR_sb = Shell Buckling Unity Ratio determined previously = 0.309

Since UR_sb <= 1, then the section can distribute the load around the opening, and the circumferential stiffener doesn't need to carry a portion of the load above the opening to each vertical stiffener.

Breach # 1 Ld 8 Circ Stiff: Maintains Roundness by Replacing Cutout Moment of Inertia:

Iy	= Stiffener Moment of Inertia for Ring Bending	= 2.25 in^4
Ico	= Mom of Inertia out of Plane for Removed Breach: Ht*Thk^3 / 12	= 1.00 in^4
Ireqd	= Req'd moment of Inertia for Stiff: Ico	= 1.00 in^4
UR_ring	= Ring Bending Mom of Inertia Check: Ireqd / Ico	= 0.444

The circumferential stiffening rings are considered as stiffening rings acting on the overall stack to resist ovalling of the stack. The evaluation of ovalling and circumferential stiffener's ability to resist that ovalling is performed elsewhere in the analysis.