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Particle Physics Division
Mechanical Department Engineering Note

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Title: NOVA FHEP Pivoter Dunnage Stability

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Reviewer(s):

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Applicable Codes: Uniform Building Code, International Building Code, AISC, BOCA, OSHA,

Abstract Summary:

This engineering note has been written to formally address questions raised during the review of the NOvA Full height engineering prototype (FHEP) pivoter in CDF. Relatively tall and slender support towers (dunnage) are used to support the table during the mating operation of the table to the upper weldment. Questions have been raised concerning the lateral stability of the dunnage towers and if they could be knocked over. This note shows that the towers are stable and unable to tip over under seismic loading.

Discussion:

Lateral loads on the dunnage tower are due to incidental contact with workers or equipment and seismic loads. Incidental contact is assumed to be less than the seismic loads. By design, the towers are intended to be loaded vertically with no horizontal load component.

Potential sources for design criteria in establishing seismically induced lateral loads include:

- FESHM (Fermilab Safety, Environmental and Health Manual)
- AISC (American Institute of Steel Construction)
- OSHA (29 CFR)
- Uniform Building Code
- BOCA (Building Officials Code Administrators)
- International Building Code (listed in the Work Smart Set)
- Fermilab Engineering Manual (see http://www.fnal.gov/directorate/documents/FNAL_Engineering_Manual.pdf)
- Fermilab Engineering Standards (see http://www.fnal.gov/faw/resources/engineeringstandards/engineeringstandards.htm)

Results from reading each potential source for lateral load design criteria:

- FESHM (Fermilab Safety, Environmental and Health Manual) does not have a chapter to explicitly address this. FESHM Chapter 1070 includes a "Work Smart" set of standards. Potential standards listed in the work smart set which may provide lateral design load criteria include the International Building Code and OSHA. Finding from reading these standards (International Building Code and OSHA) are addressed below.

- AISC (American Institute of Steel Construction) addresses design criteria in the commentary section paragraph A4. AISC does not presume to establish the loading requirements for which structures should be designed. Although used frequently as the design basis for structures at Fermilab, AISC allowable stress design (ASD) is not listed as part of the work smart set nor any other Fermilab governing standards.

- OSHA (29 CFR) lists lateral loads in 1926.652, 1926.703, 1926.651 and 1910.178 App A. These apply to excavations, excavation supports, concrete formwork and powered industrial trucks. None of these prescribe lateral load design criteria applicable to free standing structures.

- Uniform Building Code (the 1997 version is available in the PPD mechanical group library and was used in this note) addresses minimum design lateral forces and related effects in section 1630 and 1634 (for non-building structures). Calculations for the FHEP towers in accordance with UBC sections are included below. However, the Uniform Building Code is not listed as part of the work smart set nor any other Fermilab governing standards.

- BOCA (1999 version is available in the PPD mechanical group library, the 1996 version is available in the FNAL library, so the 1999 version was used in this note) addresses minimum design lateral forces and related effects in section 1610 for building structures. Calculations for the FHEP towers in accordance with BOCA sections are included below. However, BOCA is not listed as part of the work smart set nor any other Fermilab governing standards.

- International Building Code (this is not in the FNAL library and the laboratory staff attorney, Gary Leonard, has been asked to help identify what this code is and where to obtain it). Meanwhile, a requisition to purchase a copy for use in PPD/MSD has been submitted.

- Fermilab Engineering Manual does not provide minimum design lateral force criteria.

- The Fermilab Engineering Standard provides the following criteria:

2.4.2 Structural Loadings - - Mandatory

The following section addresses specific structural requirements that either will further clarify the matrix-referenced codes or site-specific variations from them.
Structural Loadings

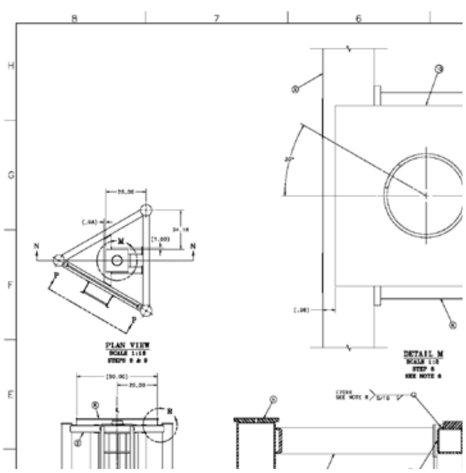
- Snow Loads: The flat roof snow load (Pf) shall not be less than 30.0 psf for any building on site.
- Wind Loads: The following shall be used for determining design wind loads
  Basic wind speed = 80 mph.
  Exposure Category = B
- Earthquake Loads: The following shall be used for determining design earthquake loads
  Av = 0.05
  Aa = 0.05
- Lateral Soil Loads: The following shall be used for determining design lateral soil loads, unless local soil tests have been performed.
  Active earth pressure coefficient, Ka = 0.5
  Unit weight of soil, [gamma] = 130 pcf
- Special Loads : The following shall be used for determining design special loads
  Down drag for vertical soil reaction on enclosures = 10%

Dunnage tower stability calculations were made using the Av earthquake loads specified in the Fermilab Engineering Standards and these are included in the calculations below.

Dunnage Tower:

Drawing of the dunnage towers are available at: ftp://www-ppd.fnal.gov/ppd-md-dwg/DWGS/MECH_466/pdf/466968-A1.pdf

Weight of the dunnage tower weldment:	3086 pounds
Height of the dunnage tower weldment:	240 inches
Height of the dunnage tower weldment center of gravity:	122.7 inches
Center to center distance of tower vertical tubes per drawing MD 466966:	62.35 inches
Diameter of the vertical tubes:	6.0 inches
Outside diameter of vertical tube end plates:	7.0 inches



BOCA in section 1610.1 lists three exceptions. Exception 3 {Buildings of structures located where the seismic coefficient representing the effective peak velocity-related acceleration (Av) is less than 0.05, are only required to comply with Section 1610.3.6.1} applies to both Ash River Minnesota and Fermilab in Batavia Illinois. In spite of this exception, the calculations for the horizontal accelerations were performed and included in this note.

UBC Section 1634 applies to non-building structures. Calculations were completed based on this section.

Dunnage towers are not anchored to the floor in CDF. Therefore, the ground is free to move horizontally during a seismic event. This would effectively reduce the horizontal forces transmitted into the dunnage tower. However, as a conservative assumption, the fully horizontal shear required by the most stringent of the above codes and standards is included in this analysis.

Conditions to evaluate include:

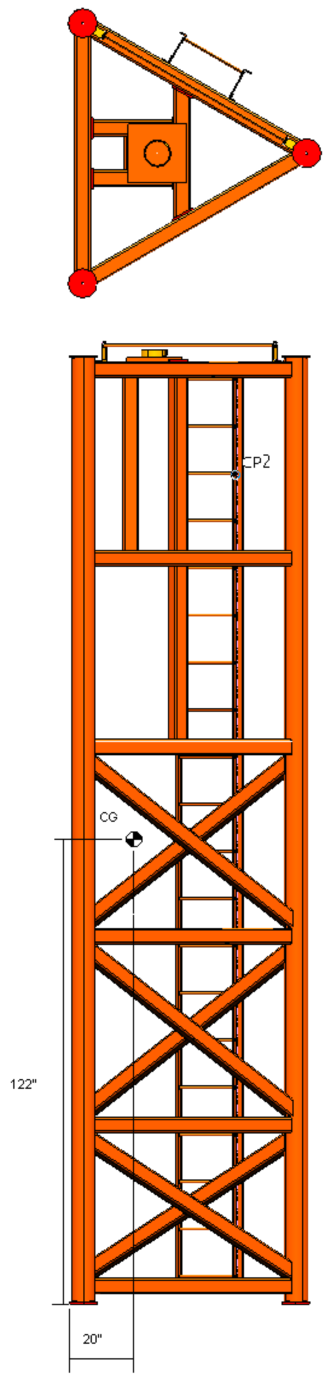
- Bare free standing dunnage tower, not supporting a load
- Dunnage tower supporting the maximum load due to the FHEP table, pallet, and FHEP detector. Under this loading condition, horizontal accelerations are resisted only by the tower. But the load (FHEP table with the FHEP detector on it) is still connected to the CDF building crane. So should the dunnage towers fail to support the load, the building crane will support the load from the FHEP table, pallet, and FHEP detector.

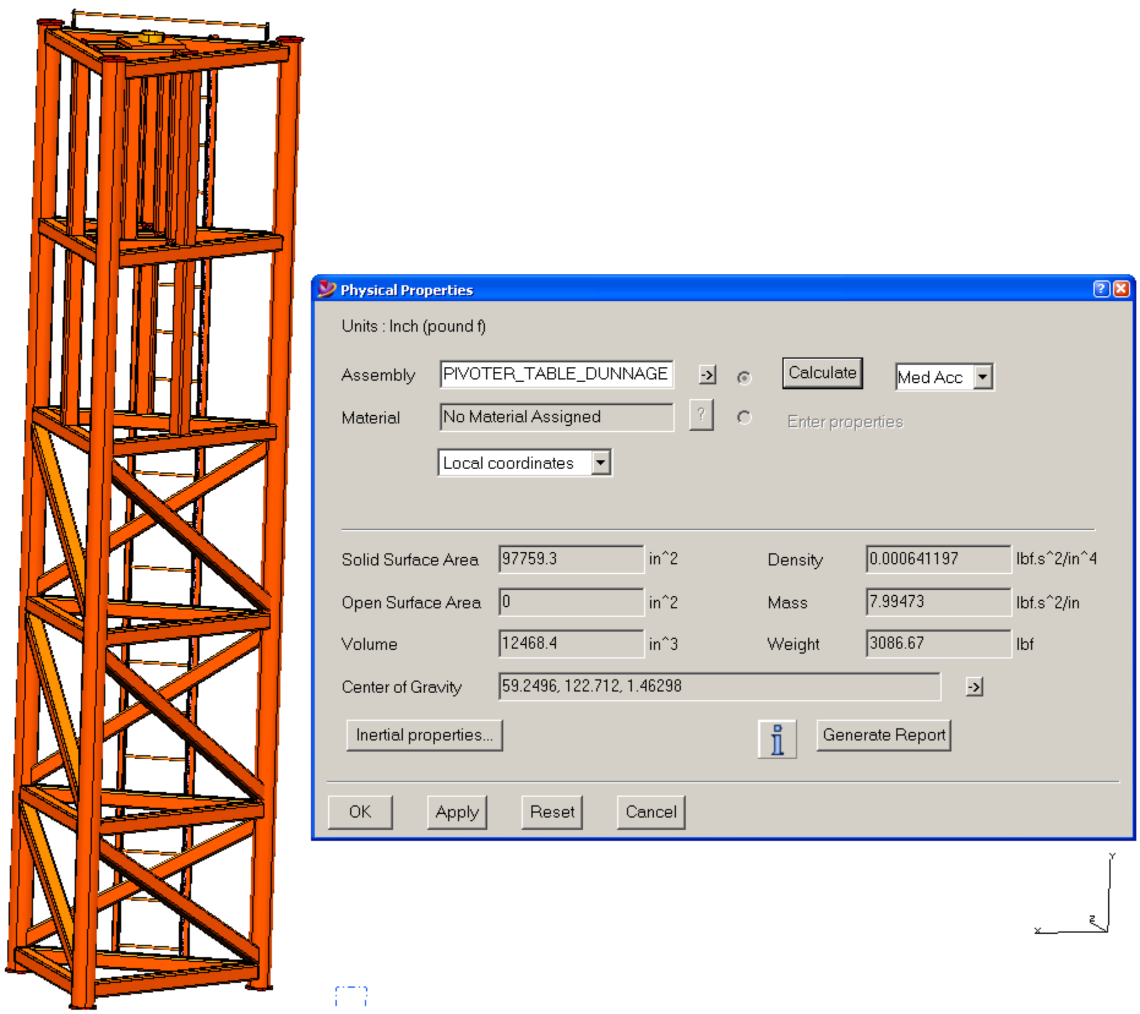
The second loading condition is a temporary loading condition anticipated to last for a few hours (perhaps overnight) while the connection between the pivoter upper weldments and the FHEP table is made.

Note that UBC, FNAL Engineering Standards and BOCA use accelerations in a form of 0.XX g. So in this note, the F = ma is simplified as F = WA where W = weight (mass time acceleration due to gravity) and A is the 0.XX value from the codes.

Both UBS and BOCA require the building structural system to be indentified and the Response modification factor (R in the calculations) is assigned based on the structural system. Note that the dunnage towers hardly represent a building as the foot print area is only about 18 square feet while the height is 20 feet. But, the structural system selected based on reading the criteria in UBC 1629 is an “Ordinary Moment Resisting Frame” and both codes assign a Response modification factor of 4.5 for this structural system.

Sketch of the tower top view and side view locating the tower C.G. and assuming tipping about the bottom left hand corner of the side view:





Screen Capture from Ideas indicating the weight (3086 pounds) and the vertical elevation of the C.G. (122.7 inches).

Calculations Result Summary:

Calculations were performed using a simple horizontal acceleration of 0.05 g per the Fermilab Engineering Standards criteria and conclude that both the unloaded dunnage tower and the fully loaded dunnage tower in CDF remain stable. Tipping does not occur.

Calculations using the methodology for buildings using codes BOCA / 1999 and UBC 1997 were performed. These are far more complicated and are primarily intended to address buildings. For example, these dunnage towers do not have a defined occupancy as does a building. Nor is it clear that the period of the towers is well represented by the formula (which is the same in both codes) used to calculate the structure period.

Still, the two building codes were used to fine a lateral force. This lateral force was applied at the center of gravity of the towers for the unloaded towers and to the top of the tower for the loaded tower. This gives an overturning moment.

Dead weight from the bare tower for the unloaded condition and for the tower and the combined weight of the table, FHEP, and pallet is assumed to act through the center of the tower. The center of the tower is 20 inches from the outside edge of the feet of the tower. This dead weight times the distance of 20 inches give a restoring moment. As long as the restoring moment exceeds the overturning moment, the dunnage tower will not tip.

Note that this simple analysis is conservative in that it ignores rotation of the rigid tower which would cause the location of the restoring force to shift to a location where the moment was greater.

Calculations for the Stability for the Dunnage Towers in CDF

Geometry:

Weight of each dunnage tower	3086	pounds
Height of each dunnage tower	240	inches
Height of each dunnage tower center of gravity	122.7	inches
Length of one side of tower	69.35	inches
Horizontal Distance from C. G. to side of tower	20.0	inches
Total Dead load for loaded tower in CDF from Engineering note 280, half the load of the front pair of towers loaded with the FHEP detector and table.	20,412	pounds
Worst Case Horizontal Acceleration from set of calculations below using each identified code or standard:	0.050	g

Tipping Calculations for unloaded tower using above Worst Case Accelerations:

Sum the moments about a line at the base of one edge of the tower:

Overturning Moment:

Worst Case horizontal Acceleration * unloaded weight:	154.3	pounds
Moment Arm (Vertical Distance from above)	122.7	inches
Overturning Moment = product of above two cells	18932.6	inch pounds

Restoring Moment:

Unloaded weight of dunnage tower from above:	3086	pounds
Moment Arm (Vertical Distance from above)	20.0	inches
Restoring Moment = product of above two cells:	61780.5	inch pounds

<u>Conclusion, restoring moment exceeds tipping moment, therefore the unloaded dunnage tower will not tip over under anticipated seismic loading</u>

Tipping Calculations for loaded tower above Worst Case Accelerations:

Sum the moments about a line at the base of one edge of the tower:

Overturning Moment:

Worst Case horizontal Acceleration * loaded weight:	1,175	pounds
Moment Arm (Vertical Distance from above)	240.0	inches
Overturning Moment = product of above two cells	281,974	inch pounds

Restoring Moment:

load + weight of dunnage tower from above:	23,498	pounds
Moment Arm (Vertical Distance from above)	20.0	inches
Restoring Moment = product of above two cells:	470,417	inch pounds

<u>Conclusion, restoring moment exceeds tipping moment, therefore the loaded dunnage tower will not tip over under anticipated seismic loading</u>

Determine the maximum horizontal accelerations using each of the identified codes or standards and use to evaluate the tipping:

From the FNAL Engineering Standards:

Acceleration Vertical, Av	0.05	g
Acceleration Horizontal, Aa	0.05	g

Tipping Calculations for unloaded tower Using Av from FNAL Engineering Standards:

Sum the moments about a line at the base of one edge of the tower:

Overturning Moment:

Worst Case horizontal Acceleration * unloaded weight:	154.3	pounds
Moment Arm (Vertical Distance from above)	122.7	inches
Overturning Moment = product of above two cells	18,933	inch pounds

Restoring Moment:

Unloaded weight of dunnage tower from above:	3086	pounds
Moment Arm (Vertical Distance from above)	20.0	inches
Restoring Moment = product of above two cells:	61,781	inch pounds

<u>Conclusion, restoring moment exceeds tipping moment, therefore the unloaded dunnage tower will not tip over under anticipated seismic loading</u>

Tipping Calculations for loaded tower Using Av from FNAL Engineering Standards:

Sum the moments about a line at the base of one edge of the tower:

Overturning Moment:

Worst Case horizontal Acceleration * loaded weight:	1,175	pounds
Moment Arm (Vertical Distance from above)	122.7	inches
Overturning Moment = product of above two cells	144,159	inch pounds

Restoring Moment:

load + weight of dunnage tower from above:	23,498	pounds
Moment Arm (Vertical Distance from above)	20.0	inches
Restoring Moment = product of above two cells:	470,417	inch pounds

<u>Conclusion, restoring moment exceeds tipping moment, therefore the loaded dunnage tower will not tip over under anticipated seismic loading</u>

From BOCA (Building Officials Code Administrators):

Seismic Hazard Exposure Group per table 1610.1.5	Group I	
Peak Acceleration Coefficient, Av per Figure 1610.1.3(1)	< 0.05	g
Use Peak Acceleration Coefficient, Av per Figure 1610.1.3(1)	0.05	g
Seismic Performance Category per Table 1610.1.7	A	

BOCA in section 1610.1 lists three exceptions. Exception 3 {Buildings of structures located where the seismic coefficient representing the effective peak velocity-related acceleration (Av) is less than 0.05, are only required to comply with Section 1610.3.6.1} applies to both Ash River Minnesota and Fermilab in Batavia Illinois.

Just for completeness, perform the calculations for the seismic analysis as if the exception did not apply:

Height of the Dunnage tower, in feet	20	feet
Value of C sub T from paragraph 1610.4.1.2.1	0.035	
Approximate Fundamental Period, T sub a = C sub T * (h)^3/4	0.331	seconds
Soil Profile type per Table 1610.3.1	S1	
Site Coefficient S based on Soil Profile type Table 1610.3.1	1.0	
Description of Basic Structural System used in Table 1610.3.3	Ordinary Moment Frame of Steel	
Response Modification Factor, R per Table 1610.3.3	4.5	
Deflection Amplification Factor, Cv per Table 1610.3.3	4	
C sub s = 1.2 * Av * S / (R*T^2/3)	0.028	
Total Dead load for unloaded tower	3086	pounds
Total Dead load for loaded tower in CDF from Engineering note 280, half the load of the front pair of towers loaded with the FHEP detector and table.	20,412	pounds
Horizontal Shear, V for unloaded dunnage tower per 1601.4.1	86.0	pounds
Horizontal Shear, V for fully loaded dunnage tower (at CDF with FHEP and Table loads) plus the shear for the unloaded tower(value from above cell) per 1601.4.1	654.7	pounds

Tipping Calculations for unloaded tower using BOCA loading:

Sum the moments about a line at the base of one edge of the tower:

Overturning Moment:		
Worst Case horizontal shear for unloaded tower	86.0	pounds
Moment Arm (Vertical Distance from above)	122.7	inches
Overturning Moment = product of above two cells	10550.8	inch pounds
Restoring Moment:		
Unloaded weight of dunnage tower from above:	3086	pounds
Moment Arm (Vertical Distance from above)	20.0	inches
Restoring Moment = product of above two cells:	61780.5	inch pounds

<u>Conclusion, restoring moment exceeds tipping moment, therefore the unloaded dunnage tower will not tip over under anticipated seismic loading using the BOCA calculated horizontal loads</u>

Tipping Calculations for loaded tower using BOCA loading:

Sum the moments about a line at the base of one edge of the tower:		
Overturning Moment:		
Worst Case horizontal shear for loaded tower	654.7	pounds
Moment Arm (Height of tower from above) - note this is a little conservative since it applies the contribution from the tower weight not at the c.g. of the tower but at the top of the tower.	240.0	inches
Overturning Moment = product of above two cells	157,139	inch pounds
Restoring Moment:		
Unloaded weight of dunnage tower from above:	23498	pounds
Moment Arm (Height of tower from above) - note this is a little conservative since it applies the contribution from the tower weight not at the c.g. of the tower but at the top of the tower.	20.0	inches
Restoring Moment = product of above two cells:	470,417	inch pounds

<u>Conclusion, restoring moment exceeds tipping moment, therefore the loaded dunnage tower will not tip over under anticipated seismic loading using the BOCA calculated horizontal loads</u>

From UBC (Uniform Building Code):

Paragraphs 1629 through 1634

For and un-loaded tower at CDF:

From UBC Table 16-N Structural Systems

Define Basic Structural System as:	Ordinary Moment Resisting Frame	
R value from Table 16-N	4.5	
Phi sub naught from Table 16-N	2.8	
Occupancy Category Used in Table 16-K	Standard	
Importance Factor, I, Given in Table 16-K	1	
Importance Factor, Ip, Specified in Table 16-K	1	
Seismic Zone applicable to FNAL and Ash River from Map in Figure 16-2	0	
Seismic Zone used in Table 16-I	1	
Seismic Zone Factor, Z, from Table 16-I	0.75	
Soil Profile Type, Sc, from in Table 16-J (FNAL location)	Sc	
Soil Profile Type, Sc, used in Table 16-Q	Sc	
Seismic coefficient, Ca, as set forth in Table 16-Q	0.09	
Wp = weight of component or element used in formula		
Total Seismic Dead Load, W, for un-loaded tower	3086	pounds
Ct from UBC for a moment-resisting frame	0.035	
Height of dunnage tower, hn in feet	20	
Period of the dunnage tower, T = Ct * (h^3/4)	0.33	seconds
Lateral Force, Fp per eqn 34-2 in UBC section 1634.5	155.5344	pounds

Tipping Calculations for unloaded tower using UBC loading:

Sum the moments about a line at the base of one edge of the tower:

Overturning Moment:		
Worst Case horizontal shear for unloaded tower	155.5	pounds
Moment Arm (Vertical Distance from above)	122.7	inches
Overturning Moment = product of above two cells	19,084	inch pounds
Restoring Moment:		
Unloaded weight of dunnage tower from above:	3086	pounds
Moment Arm (Vertical Distance from above)	20.0	inches
Restoring Moment = product of above two cells:	61,781	inch pounds

<u>Conclusion, restoring moment exceeds tipping moment, therefore the unloaded dunnage tower will not tip over under anticipated seismic loading using the BOCA calculated horizontal loads</u>

Tipping Calculations for loaded tower using UBC loading:

Total Seismic Dead Load, W, for un-loaded tower	23,498	pounds
Lateral Force, Fp per eqn 34-2 in UBC section 1634.5	1,184	pounds
Sum the moments about a line at the base of one edge of the tower:		
Overturning Moment:		
Worst Case horizontal shear for unloaded tower	1,184	pounds
Moment Arm (Vertical Distance from above)	240.0	inches
Overturning Moment = product of above two cells	284,229	inch pounds
Restoring Moment:		
Unloaded weight of dunnage tower from above:	23498	pounds
Moment Arm (Vertical Distance from above)	20.0	inches
Restoring Moment = product of above two cells:	470,417	inch pounds

<u>Conclusion, restoring moment exceeds tipping moment, therefore the unloaded dunnage tower will not tip over under anticipated seismic loading using the BOCA calculated horizontal loads</u>