Fermilab

Particle Physics Division

Mechanical Department Engineering Note

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Project: Xenon Test Station , Structural analysis

Project Internal Reference: PPD/MD/PAB

Title: Xenon Test Station @ PAB

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Reviewer(s):

Key Words: Xenon Test Station, PAB, Hoists

Abstract/Summary:
This is a structural analysis documenting the hoists installed at PAB for the Xenon Test. This analysis concludes the actions that need to be taken to assure safe operation of these hoists.

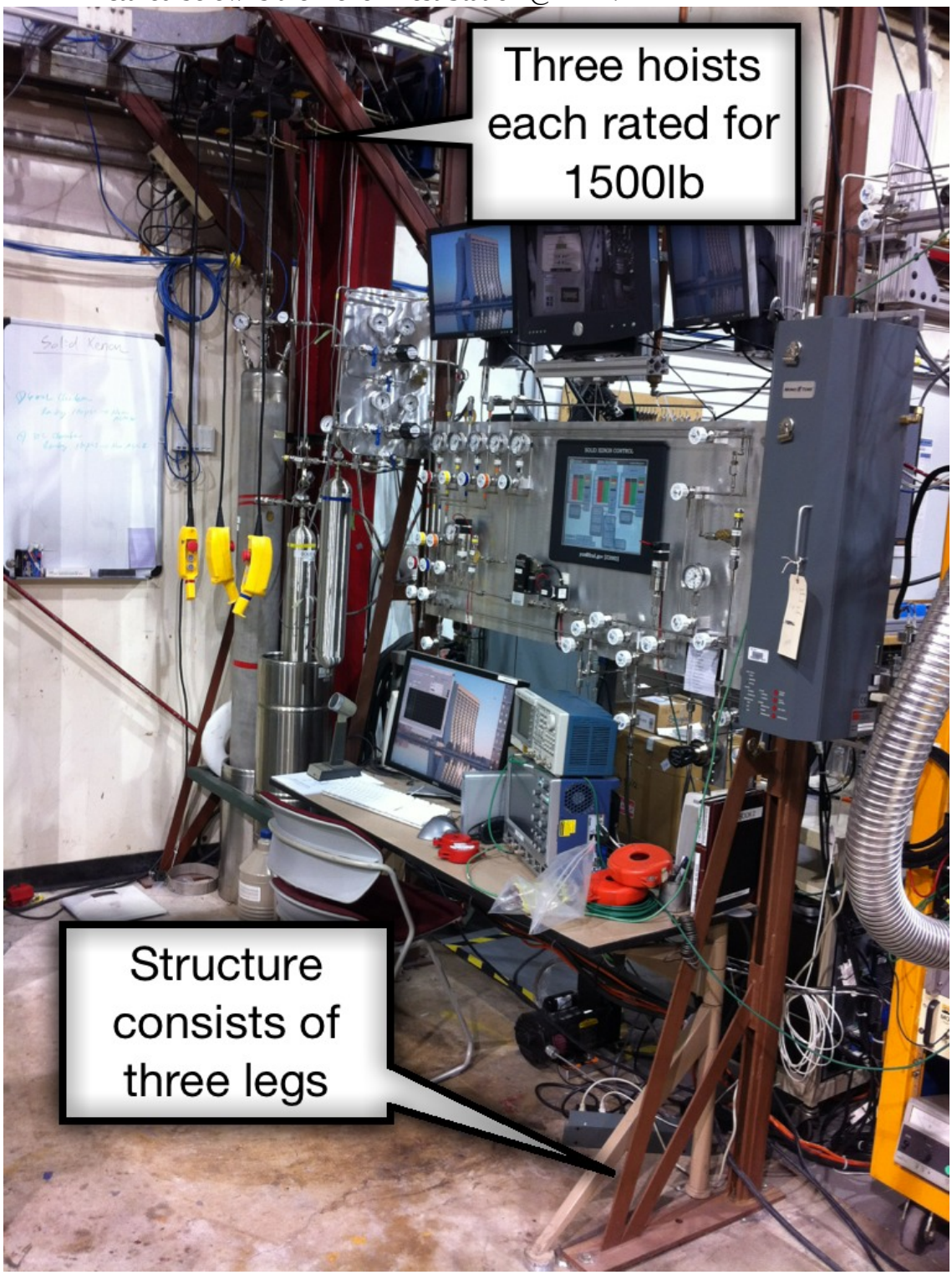
Applicable Codes:
Fermilab Environment, Safety, and Health manual, chapter 5021

Xenon Test Station
@ PAB

K. Krempetz Nov. 2011

Introduction

Pictured below is the Xenon Test Station @ PAB.



This station consists of a unistrut structure which supports a valve/manifold panel and 3 electric hoists. This structure is held to the floor by 6 bolts, each 1/2” in diameter mounted in the concrete floor with Hilti anchors. There are 3 unistrut legs/columns, between one set of legs/columns is the valve/manifold panel and between the other set of legs/columns are three electric hoists. These hoists are support from two ½” thick, 5” wide steel plates as shown in the pictures below.

The purpose of the electric hoists is to lower vessels of xenon into open mouth liquid nitrogen dewars. These vessels with the xenon contents weigh from 30 to 60 lbs. These vessels typically stay on the hooks of these hoists long periods of time, in terms of months.

The unistrut structure was designed in the field with very experience people gathering and reusing old components to make this test station. The components were chosen very conservatively. Also the risks associated with the structure failing is very small. To help the schedule of the project it was thought that assembling the components and then doing an "as built" engineering check was the most efficient way to proceed. Given the low hazard potential the "graded approach" is being implemented and a detailed engineering design and analysis is not thought to be necessary.

Summary Engineering Check of the Structure.

Some calculations are presented in Appendix 1. The structure can be broken down into two main components, the 3 support columns and the 2 spanning plates which the three electric hoists are supported from. Also, there are two main safety concerns; does the structure break or fail and can the structure tip over.

Support Columns

The load on the three support columns is the weight for the valve/manifold panel which is estimated at 150 lbs and the three hoists each weighing 50 lbs plus the load of the three vessels and xenon which is 60 lbs, 30lbs and 30lbs respectively. Therefore the total load on the columns is 420 lbs, we will just round this to 500 lbs. Each column is made from B22A unistrut with an additional ¼" x 2" steel plate on each side attached by a 2" skip weld every 12". If we ignore the welded plates on the unistrut, Euler's Buckling equation for one end free and the other end fixed and a span of 120"gives a load of 6,851 lbs for the bucking force needed. Clearly the support legs/columns do not have a buckling issue.

Since the hoists are offset from the column, they apply a moment on this column. This puts a bending stress on the unistrut of 796 psi. The B-line unistut catalog recommends keeping the stresses below 25,000psi. This is base on the fact that the material unistrut is made from has a minimum yield strength of 33,000 psi. Therefore it is very clear the support columns can handle the compressive load and the bending load.

Flat Plates

Two ½"x5 plates support the three hoists. The span between these plates is 44". In appendix 1 is a calculation for a simply support beam with three concentrated loads. The maximum stress in these plates is found to be about 4,400 psi. These plates are most likely to be A36 steel which has an ultimate stress of 58,000 psi and yield strength of 36,000 psi. Typically for bending the appropriate safety factor is .6 of yield or 21,600 psi allowable stress. Since we are not positive this is A36 steel and other steels do have lower yield strengths, it is believed staying below about 10,000 psi is appropriate. The 4,400 psi stress in the plates is over a factor of two lower than the limit which was considered appropriate therefore the plates are able to handle the loads.

Structure Stability

The structure is held to the floor by six ½-13 bolts. Since it not known what class the bolts are, we will assume a very conservative allowable stress in the bolts of 10,000psi. Then each bolt is able to hold 1419 lbs. Given the structure geometry this translates into the structure being able to withstand a 260lb sideways load at the top of each column and still not tipping over. The structure is stable.

Hoist

The 3 electric hoists were supplied by Northern Industrial Tool and were just purchased (new). Their model number is HGS750/1500 and with the pulley hook they are rated to lift 1500 lbs. The gear box of these hoists has a worm gear, which is a self locking device therefore no brake is incorporated in the hoist. This is safe design which is known to be very reliable as a braking system.

Technically speaking any hoist falls under the scope of the FESHM 5021, but in this case since the load these hoists are carrying are so much smaller than the rated load and the risks and hazards associated the load falling to the floor is so low an exemption for this situation is reasonable.

Summary

A quick engineering analysis indicates the structure is capable of handling the loads which are planned on being applied to it. The hoists do fall under FESHM 5021 but do to the circumstances following this standard would not be cost efficient or reasonable. The recommendation is to have a small set of administrative constraints. Below are the suggested constraints.

1) Have a specific JHA written up for operation of the 3 electric hoists.
2) Lock out the hoists and only allow trained people in the Xenon test station who have signed the above JHA to operate the hoists.
3) Place on the structure a sign indicating the maximum lifting load of each hoist.

Appendix 1

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ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

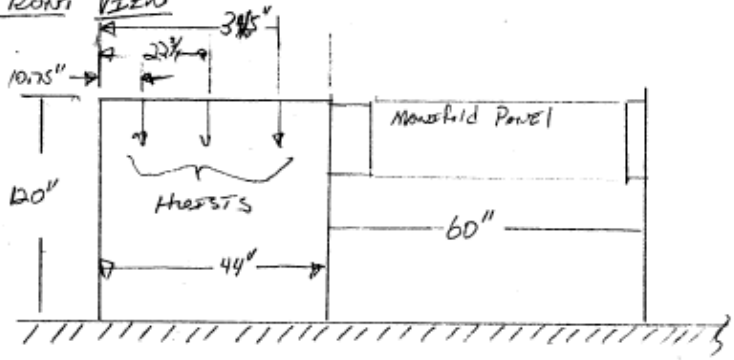
SUBJECT: XENON TEST STATION @ PAB

NAME: K. KREMPETS

DATE: NOV-2011

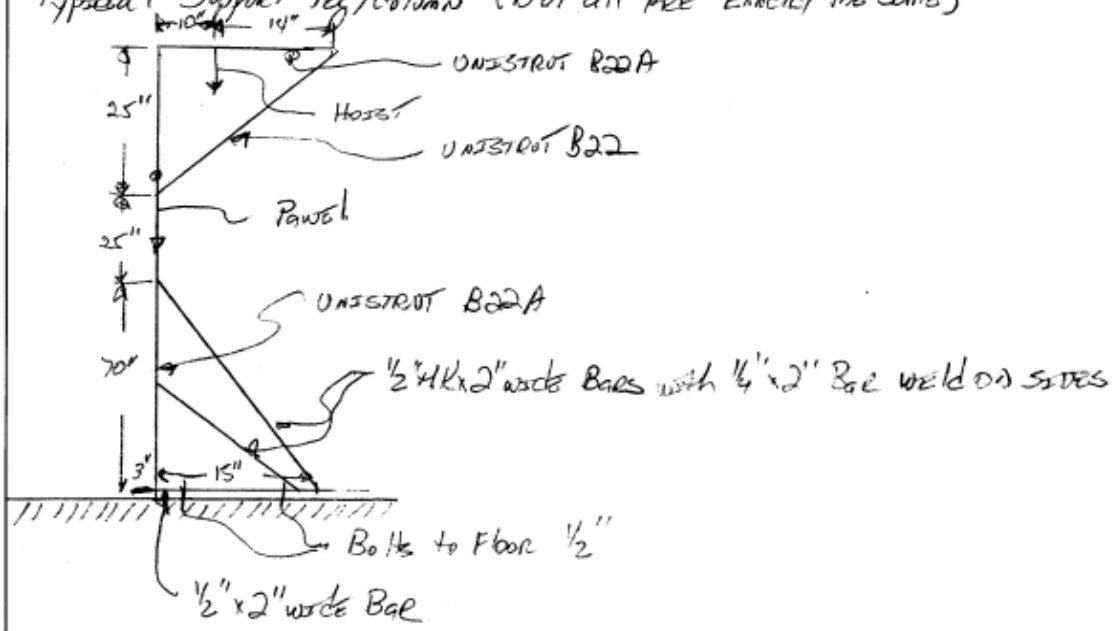
REVISION DATE:

FRONT VIEW



SIDE VIEW

Typical Support Leg/Column (NOT ALL ARE EXACTLY THE SAME)



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SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: Sample Frame Analysis
Manifold Panel

NAME:

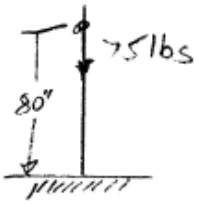
DATE:

REVISION DATE:

CG of Manifold Panel @ column, basically

just column load on unistrut.

Manifold Panel 150 lbs each support takes 75 lbs



Euler Buckling Eq

$$P = \frac{\pi^2 EI}{(KL)^2}$$

K = 1.2 free end & fixed
E = 30x10⁶ psi
I = .4798 from B-line
L = 80"

$$P = \pi^2 \cdot 30\times10^6 \cdot .4798 / (1.2 \cdot 80)^2 = 15{,}414 \text{ lbs}$$

NOTE: column section is B22A with 1/4"x2" Bar skip weld 2"x12" not include in buckling calculation. These bars make the column stronger.

If the hoist loads are included:

$$P = \frac{\pi^2 \cdot 30\times10^6 \cdot .4798}{(1.2 \cdot 120)^2} = 6{,}851 \text{ lbs}$$

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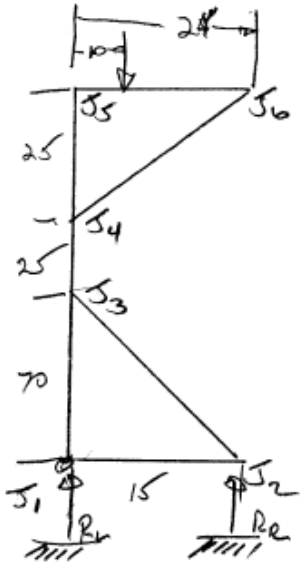
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: Simple Frame Analysis
Hoist

NAME:
DATE:
REVISION DATE:



load = Hoist + Vessels

load = (50+60)+(50+30)+(50+30)

Load = 270 lbs or 135 lb/column

$\Sigma M = \emptyset$
about joint J_1

$10 \cdot 135 + R_R \cdot 15 = 0$ $\quad R_R = 90$ lbs

$\Sigma F_y = \emptyset$
$135 - 90 = R_L$ $\quad R_L = 45$ lbs

$\Sigma M = \emptyset$ about joint J_5

$10 \cdot 135 + 24 \cdot J_{6y} = 0$ $\quad J_{6y} = 56.25$ lbs

$\Sigma F_y = 0$
$135 - 56.25 = J_{5y}$ $\quad J_{5y} = 78.75$ lbs

Force in Component (J_5 & J_6)

angle = $\tan^{-1}(25/24) = 46.2°$

Compression Force $56.25 / \sin(46.2) = 77.9$ lbs

Force in Component (J_5 & J_6)

tension Force $\cos 46.2° \; 77.9 = 53.9$ lbs

Force in Component (J_4 & J_5) = 78.75 lbs

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
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Force in component $(J_1 : J_3) = 45$ lbs

Force in component $(J_2 : J_3)$

angle $= \tan^{-1}(70/15) = 77.9°$

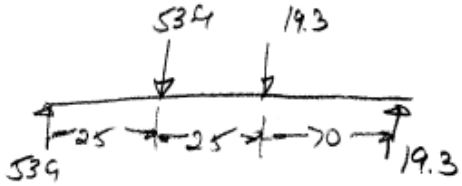
$90/(\sin 77.9) = 92.0$ compression

Force in component $(J_1 : J_2)$

tension $92.0° \cos 77.9 = 19.3$ lbs

Bending Moment in the column

or



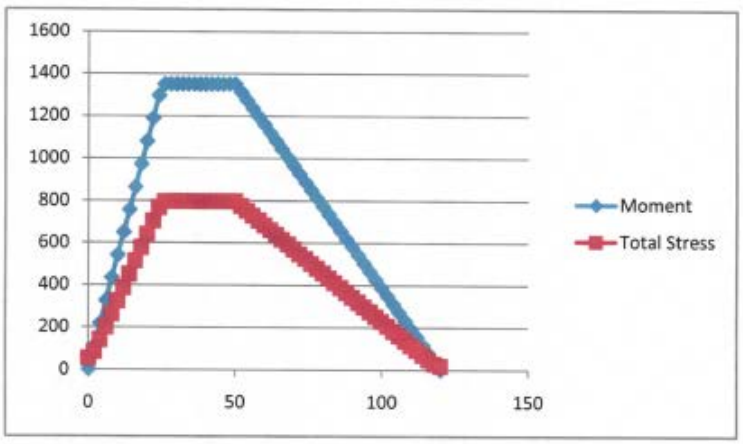
Below is a spreadsheet which determines the stress in the Beam

Simply Support Beam
K. Krempetz Nov,2011
2 concentrated Loads

Load 1 (lbs)	-53.9
Distance from left support (in)	25
Load 2 (lbs)	-19.3
Distance from left support (in)	50
Total Length of Beam(in)	120
Beam Cross Section	
area	1.124
Section Modulus	0.5905
Calculations	
Total Load	-73.2
Rr	19.3
Rl	53.9

	X	Moment	Bending Stress	Shear	Shear Stress	Total Stress
Moment	0	0	0	54	48	54
	2	108	64	54	48	83
	4	216	127	54	48	138
	6	324	191	54	48	199
	8	431	255	54	48	260
	10	539	318	54	48	323
	12	647	382	54	48	386
	14	755	446	54	48	449
	16	863	510	54	48	512
	18	971	573	54	48	576
	20	1079	637	54	48	639
	22	1186	701	54	48	703
	24	1294	764	54	48	766
	26	1348	796	0	0	796
	28	1348	796	0	0	796
	30	1348	796	0	0	796
	32	1348	796	0	0	796
	34	1348	796	0	0	796
	36	1349	796	0	0	796
	38	1349	796	0	0	796
	40	1349	796	0	0	796
	42	1349	796	0	0	796
	44	1349	796	0	0	796
	46	1349	796	0	0	796
	48	1349	797	0	0	797
	50	1349	797	-19	-17	797
	52	1310	774	-19	-17	774
	54	1272	751	-19	-17	751
	56	1233	728	-19	-17	729
	58	1195	706	-19	-17	706
	60	1156	683	-19	-17	683

62	1118	660	-19	-17	660
64	1079	637	-19	-17	638
66	1041	614	-19	-17	615
68	1002	592	-19	-17	592
70	964	569	-19	-17	569
72	925	546	-19	-17	547
74	886	523	-19	-17	524
76	848	501	-19	-17	501
78	809	478	-19	-17	478
80	771	455	-19	-17	456
82	732	432	-19	-17	433
84	694	410	-19	-17	410
86	655	387	-19	-17	387
88	617	364	-19	-17	365
90	578	341	-19	-17	342
92	540	319	-19	-17	319
94	501	296	-19	-17	296
96	463	273	-19	-17	274
98	424	250	-19	-17	251
100	385	228	-19	-17	228
102	347	205	-19	-17	206
104	308	182	-19	-17	183
106	270	159	-19	-17	160
108	231	137	-19	-17	138
110	193	114	-19	-17	115
112	154	91	-19	-17	93
114	116	68	-19	-17	71
116	77	46	-19	-17	49
118	39	23	-19	-17	30
120	0	0	-19	-17	19



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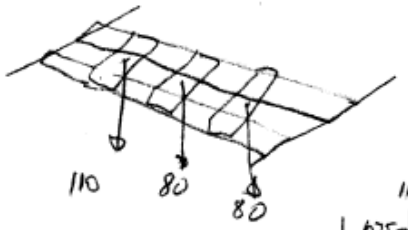
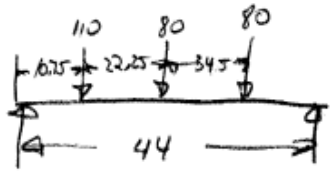
Flat Plates support 3 Hoists

Hoist weigh = 50 lbs





Spreadsheet below to calculated Beam Stresses.

Simply Support Beam
K. Krempetz Nov 2011
3 concentrated Loads

Load 1 (lbs)	-110
Distance from left support (in)	10.75
Load 2 (lbs)	-80
Distance from left support (in)	22.75
Load 3 (lbs)	-80
Distance from left support (in)	34.5
Total Length of Beam(in)	44
Beam Cross Section	
Height	0.5
Wide	10
Calculations	
Total Load	-270
Rr	$131.0
Rl	$139.0
Moment of Inertia	0.1042

X	Moment	Bending Stress	Shear	Shear Stress	Total Stress
0	0	0	139	28	139
2	278	667	139	28	682
4	556	1335	139	28	1342
6	834	2002	139	28	2007
8	1112	2669	139	28	2673
10	1390	3337	139	28	3340
12	1531	3674	29	6	3674
14	1589	3814	29	6	3814
16	1647	3953	29	6	3953
18	1705	4092	29	6	4092
20	1763	4232	29	6	4232
22	1821	4371	29	6	4371
24	1779	4270	-51	-10	4271
26	1677	4026	-51	-10	4026
28	1575	3781	-51	-10	3781
30	1474	3536	-51	-10	3537
32	1372	3292	-51	-10	3292
34	1270	3047	-51	-10	3048
36	1048	2515	-131	-26	2518
38	786	1886	-131	-26	1890
40	524	1257	-131	-26	1264
42	262	629	-131	-26	642
44	0	0	-131	-26	131

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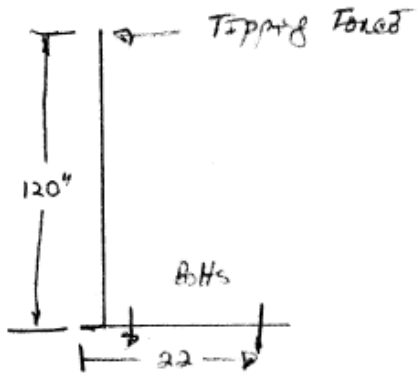
STRUCTURE Stability

½-13 BoH STRESS AREA = .1419

IF ASSUME 10,000psi allowable STRESS ON BoH (VERY CONSERVATIVE)

$F = 10{,}000 \cdot .1419 = 1419$ lbs



$\Sigma M = 0 \quad 1419 \cdot 22 = 120 \cdot X$

$X \cong 260$ lbs tipping Force