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Proposal for a new B-Target Room Tunnel Layout

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1 Abstract

Proposal for a new B-Target Room Tunnel Layout. REZA ESFANDIARI (San José State University, San José, CA 95192) CARSTEN HAST (SLAC National Accelerator Laboratory, Menlo Park, CA 94025)

Several groups at SLAC National Accelerator Laboratory are currently working on a RF Modulator prototype for a future linear collider known as the International Linear Collider (ILC). The ILC runs using about a 1000 Klystrons which create high power carrier waves for the particle acceleration. Klystrons receive their electrical input power from modulators. In order to move beyond the prototype phase, the laboratory might expand its ground base further down a tunnel located at the End Station B (ESB) in order to house four new Klystron Modulator Test Stations. This area is known as the B-Target Room Tunnel, and the task was to redesign the tunnel layout for the upcoming changes. The project first began by collecting substantial amount of information about the prototyped project, the tunnel and the researchers' feedback of what they would like to see in the upcoming design. Subsequent to numerous planning and presentations, one particular design was. Calculations for this design were then performed for the most complex aspects of the project. Based on the results of the calculations, specific sample beams, welds, bolts and materials were chosen for the possible future construction.

2 Introduction

The ILC is the next big thing in particle physics now that the Large Hadron Collider(LHC) has been built and is becoming operational. ILC will consists of two linear accelerators, one that has electrons and another that has positrons, which they collide the electrons and positrons at the speed of light [1]. Two machines, labeled as the Klystron and the Marx Modulator, play the lead role in making the particle happen. The Marx Modulator acts as the power supplier for the Klystron, Klystrons are linear beam vacuum tubes that produce high power carrier waves (RF waves) for particle accelerators [2], refer to Figure 1 for picture of the Klystron and Marx Modulator. A prototype Marx Modulator and a commercially available Klystron are currently placed and operating at the End Station B at SLAC National Accelerator Laboratory. However, in order to move beyond the current limitations, and in the hopes of pushing reliability and operational availability beyond the current values, the laboratory is in need of an expansion. At the present time, there is only one test stand that consists of the Klystron and the Marx Modulator, and the plan is to expand to four, maybe five, stations in the future. With this increase of equipments, however, comes the need for a new operating space. End Station B has a tunnel at its end that has been used for storage of depleted accelerator parts. My task was to redesign the layout of this tunnel so it could house the next generation of experiments. My work first began by putting together a proper blueprint of the place. Then, I talked to researchers, management and investors to understand not only the details about their operations, but also what they wanted in the tunnel in order to come up with an essential design. Lastly, I was to come up with the calculations needed for the construction and match those calculations with appropriate tools and materials to use.

3 Method & Procedure

I. Data Collection

The Stanford Linear Accelerator Center (SLAC) no renamed to SLAC National Accelerator Laboratory was built in 1966 with designs and developments beginning in the 1950s. The End Station B was amongst the structures that were first built in SLAC in the late 1960s. Since at those times computer assisted drafting programs (CADs) were not yet developed, all SLAC blueprints were hand drawn by architects. The labeling and numbering system of the blueprints back then were not as efficient as today, and they also were not digitally stored. Within the last decade, all available blueprints were scanned and stored onto SLAC's website. As a result, the first stage was to put together a blueprint of the B-Target Room Tunnel that was as complete as possible since many pages of the blueprints were not available. Moreover, in some cases, certain measurements needed to be re-measured. One of those instances was the slope of the tunnel's floor, which according to the blueprints, had a slope of 1%. With the use of Plane Surveying method and equipments, such as the theodolite, the ground slope level was measured for conformation. Additionally, certain measurements that were not provided by blueprints needed to be manually measured. For example, the cranes which were hung on the ceiling were not properly labeled and dimensioned in the blueprints, thus were in need of a measurement along with their position relative to the walls and floor. Once the blueprint packet was put together and all the blanks were filled in, the proper measurements were then used for the upcoming designs.

II. Design Proposal & Codes

The second task was to come up with a design sketch that implemented the machine stations and met certain criteria specified by the researchers at the ESB along with the Departmental Manager. I spent a great deal of time talking with these people in order to gain an overall knowledge of their operations along with their visions of what they like to see in the upcoming design. Many workers addressed that it was rather difficult for them to perform maintenance on the upper portion of the Klystron since it goes as high up as eight feet. The Departmental Manager preferred a design which would place the Klystrons on a higher elevation with respect to the Marx Modulators, and part of the overall criteria was to ensure there is space available for future storage.

The next step was to continuously come up with different designs and present them to the departmental manager until he was satisfied with a few propositions. The chosen designs were then compiled into a PowerPoint presentation and presented to the lead managements of the ESB operation. In the final design, it was agreed to place 12’ long beams on the high ledge of the tunnel (11’-4” high from the floor) placed perpendicularly to the walls. These beams were placed at 6’ intervals along the 108’ long tunnel to serve two functions; one function was to act as the base for the floor placed 11’-4” high up, and second function was to act in supporting the Klystrons. At four evenly spaced intervals, beam-to-beam frames were attached to the underneath of the beams essentially creating cages which would act as the housing for the Klystrons. This housing would also partly sit on the lower ledges of the wall (7’-8” high from the floor) for extra support. The purpose of this design was not only for storage, but also to allow people to get on the floor and perform maintenance on top portions of Klystrons which now extend out about 5’ above the placed floor. The Marx Modulators were placed directly beneath the Klystron on the ground. Additional small details were applied such as placing a tunnel wide pipe on the top left portion of the tunnel, and also placing a stair for each end of the floor; refer to Figure 2 for the final design.

In addition, in the process of coming up with these designs, two major Codes had to be referenced and used as guidelines. These sources included the California Building Codes and the Occupational Safety and Health Administration (OSHA). The California Building Codes called a 4’ clearance from the top of the machines to the ceiling, and placing the Klystron any higher than the proposed design would violate the clearance requirement. The codes require the placed floor to be split into 6’ segments and individually placed in the 108’ long tunnel. Furthermore, it is required that the placed floor would not touch the walls, and a half inch space needs to be left between the floor edges and the wall and then to be anchored in [3]. In addition to the building codes, the OSHA requirements had to be met. Any structures built for the public use, where people are expected to be going on and off the structure, will need to comply by the OSHA standards. In our case, the stairs we placed had to meet the OSHA standard to ensure the safety of the public. With the OSHA standards, stairs could only have an incline between 40°-60°, and the stairs must have the minimum width of 22”. In addition, any structure which requires a stair access also needs a secondary stair passage for emergencies. The emergency stair, however, could be a spiral stair whereas the main stair cannot be. As a result, 15’ of space were kept clear at each end of the tunnel on the design to guarantee enough space for the stairs.

III. Calculations

Once the main structures of the design was finalized and set, many calculations were needed to be computed for all aspect of the design. To begin with, simple calculations were done to calculate the center of gravity (eq.1), and moment of inertia(eq.2),

$$\frac{\sum m_i r_i}{\sum m_i} \qquad (1)$$

$$\int r^2 dm \qquad (2)$$

and a general estimation of the Klystron weight along with the live and dead loads that will be placed into the structure. All calculations were done twice, once under static load which took into account only the live and dead loads, and a second time with the assumption of an earthquake load. It is important to note that the weight of the materials used for the structures were neglected due to the large safety margins that were provided in the calculations. SLAC National Accelerator Laboratory has its own formula for computation of earthquake loads for experimental equipment which is not covered by the building code (eq. 3),

$$(1.5) \times DeadLoad + E \qquad (3)$$

where *E* is the horizontal seismic force. All earthquake calculations were under the assumption of an earthquake acceleration force of 0.7g, a category D earthquake resistant measure [4].

Under these two loads assumption, the calculations were started by calculating the reactions of the beam placed on the high ledge using eq. 4,

$$\frac{Wb}{l}, \frac{Wa}{l} \qquad (4)$$

where *W* is the weight of the load, *l* is the length of the beam and *a/b* are the distances from the load to opposite ends of the beam. The bending moment (eq. 5) and Shear (eq. 6) were then calculated at the center of the beam,

$$\sum M = Fd \qquad (5)$$

$$\tau = \frac{F}{A} \qquad (6)$$

where *F* is the force acting on the load, *d* is the perpendicular distance of the load to the point of the moment and *A* is the cross-section area of the applied load. The maximum bending moment and the maximum shear were also calculated for the beam and their diagrams were generated on the computer (Figures 4-7). Using Newton’s second law (eq. 7), the load on each frame connected to the main beam were distributed amongst the four axial points,

$$\sum F = ma \qquad (7)$$

where *m* is the mass and a is the acceleration. Stress at loads were then calculated using eq. 8,

$$\frac{Wab}{Zl}. \qquad (8)$$

Upon completion of the calculations mentioned above, more specific earthquake resistance calculations were performed. First the Base Shear (V) was calculated (eq. 9),

$$\frac{WSa}{g_c} \qquad (9)$$

where *W* is the weight affected by the earthquake, Sa is the earthquake acceleration and *g* is the gravity.

Then, the Horizontal Seismic Force (E_h) and the Lateral Seismic Force (E_l) were taken into consideration, using eq. 10 and 11.

$$E_h = \rho Q_E \qquad (10)$$

$$E_l = \frac{ma}{g_c} \qquad (11)$$

where Q_E is the effect of horizontal seismic force form base shear, and ρ is the redundancy factor, which is 1.3 in our case based from *Minimum Design Loads for Buildings and Other Structures* [5]. After understanding the Horizontal Seismic Force, one can then apply it to find whether or not the Klystron would overturn during an earthquake, and if so, with what force (eq. 12),

$$OverTurning = \sum M_{overturning} - \sum M_{resisting} \qquad (12)$$

where the initial resisting moment is often the weight, and the overturning force is the earthquake. Once these main calculations were done, few additional minor calculations were completed using eq. 13-15 to determine the Torsion Moment, Building Period and Stiffness of the beam under an earthquake for future reference,

$$M_{torsional}(Fi) = Ve, \qquad (13)$$

$$T = 2\Pi\sqrt{\frac{m}{g_c}}\;, \qquad (14)$$

$$K = \frac{48EI}{L^3}\;. \qquad (15)$$

4 Results

I. Results of the Calculations

All following results are based on earthquake load, for static load refer to Table 1.

Reactions of Main Beam = 1,149lb on the right (away from the Klystron) &

4,366 lb on the left (near the Klystron cage)

Bending Moment @ Center = 6,894 lbf

Maximum Bending Moment = 9,192 lbf

Shear @ Center = 1,149 lb

Maximum Shear = 4,366 lb

Base Shear (V) = 4,200 lbf

Horizontal Seismic Force (E_h) = 5,460 lbf

Lateral Seismic force (E_l)= 6,618.5 lbf

Torsion Moment = 39,711 lb.ft^2

Stress @ Load = 8,987 PSI

Overturning = 165 lbf

Load on each frame connected to Beam = 2757.5 lb

II. The Stairs

To meet the OSHA Standard, the stair was designed at an incline of 45°. Each step is 1’ high, 1’ long and the width is 25”. The stair has the height of 11’ foot and 11’ long along the tunnel.

III. Applying the Results

Subsequent to finishing all the computations, the results are matched with the proper materials. The task at hand first started by deciding what beam to choose that could carry the heavy load of the Klystron stations during earthquakes, and could face acceptable deflections under the total load. Since the beam would go under a maximum bending moment of 9,192 lbf, a W6 x 20 (Fy= 36ksi) beam was chosen, refer to Table 2 for full detail on the W6x20 beam. These beams have an allowable bending moment of 27,000 lbf, which provides a great margin of safety. Following this decision, it had to be decided how to connect the beam-to-beam frames onto the main beam to create the cage for the Klystrons to sit in. Since each point of the beam-to-beam frame connection needed to hold 2757.5 lbs, a Weld B Capacity of Size =1/4” was chosen which holds 14,000 lbs, leaving a large margin of safety. Due to the 5,460 lbf Horizontal Seismic Force, the floor must be anchored into the concrete walls. Each beam set that holds a Klystron needs to be anchored at each end with a carbon steel HDI ¾” x 4” anchor to resist the horizontal forces. Lastly, since the Klystron would, it will also be attached to the Beam at the point where it is at the same height as the beam. Since this force is only 165 lbf, close to negligible, no details were worked out in the proposed layout, refer to Figure 8 for the final specification of the Klystron structure.

5 Conclusion & Future Work

In conclusion, under the direction of Carsten Hast, I have gained a lot of valuable experience as to how I can take what I have learned in school and apply it to a real life project. I have learned how to tackle a challenge which I had no idea how to solve, and what sources I should use when I hit a dead end on those challenges. And more importantly, it was the role of networking and communication which made this project a worthwhile experience. Never before had I realize the immense challenge of communication between scientists and engineers, and its importance to work towards a common goal.

Looking towards the future, while this design idea is now very much developed, it is far from being built. The design and the calculations need to be checked through a licensed Structural Engineer, along with approval of the fire marshall, before the construction can begin. It is my hope that one day this design will be built primarily with the framework that I have constructed and I look forward to seeing it built someday.

6 Acknowledgement

This effort would not have been possible without funding from the Department of Energy and the SULI program at the SLAC National Accelerator Laboratory. I would like to thank Steve Rock, the SULI Program Director, who made it all possible, and Carsten Hast, my mentor, whose passionate support and guidance made the completion of this project feasible. Special thanks to Keith Jobe for tolerating me, along with the rest of the incredible staff working at the ESB and the Next Linear Collider Test Accelerator.

7 References

[1] ILC. (2002). International Linear Collider. [Online]. Available: http://www.linearcollider.org/cms/?pid=1000000

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[3] International Code Council. (2007). California Building Code. ICC, United States. [Online]. Available:http://ecodes.citation.com/cgiexe/cpage.dll?pg=x&rp=/nonindx/ST/ca/st/b200v07/index.htm&sid=2009080509553824946&aph=0&cid=stan++++++++++++++++&ref=/nonindx/ST/ca/index.htm&uid=icsc0501&clrA=005596&clrV=005596&clrX=005596

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[6] American Institute of Steel Construction. (1991, January). *Manual of Steel Construction: Allowable Stress Design*. (9th ed.) [Book].

8 Tables and Figures

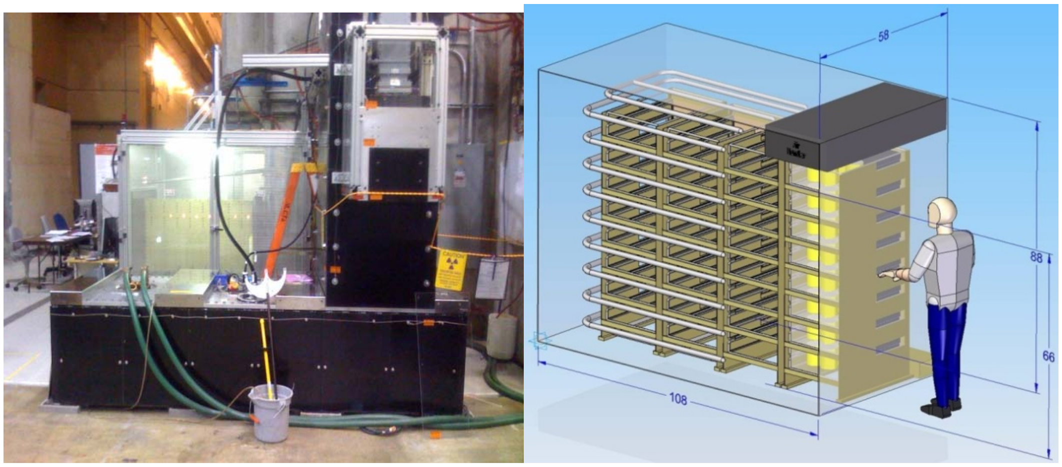


Figure 1: To the left: A Klystron with its tank that shields the radiation. To the right: Marx Modulator which powers the Klystron.

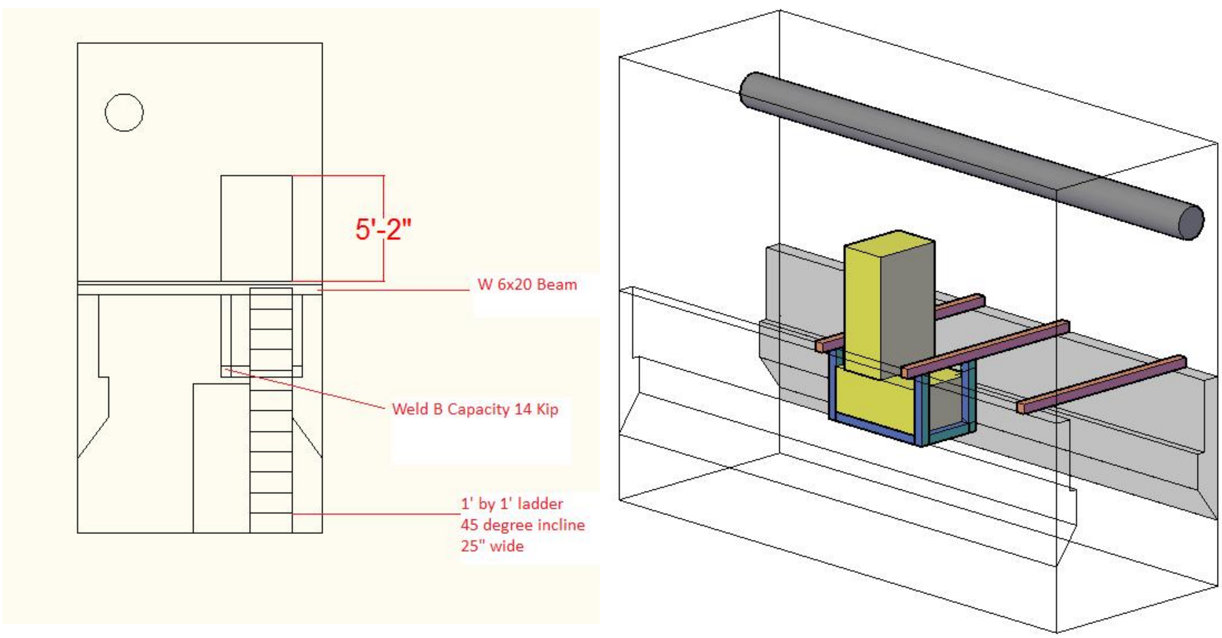
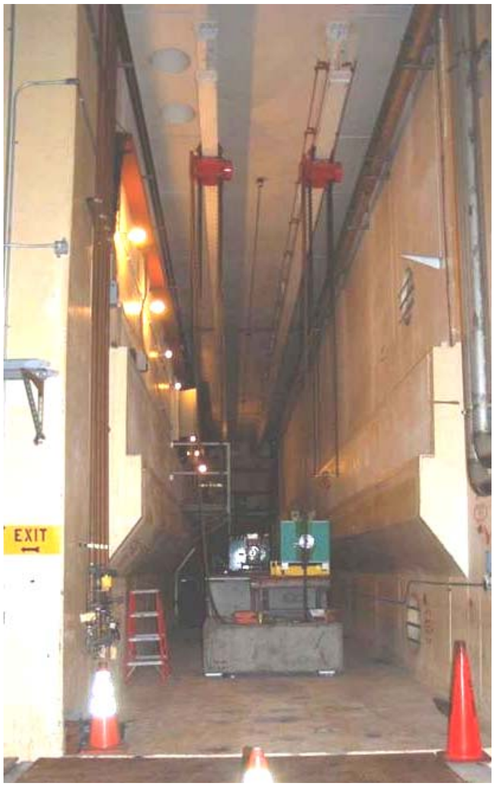


Figure 2: To the right, is the final design of one station of a Klystron in the tunnel. To the left, is the cross-sectional view of the final design looking into the tunnel.



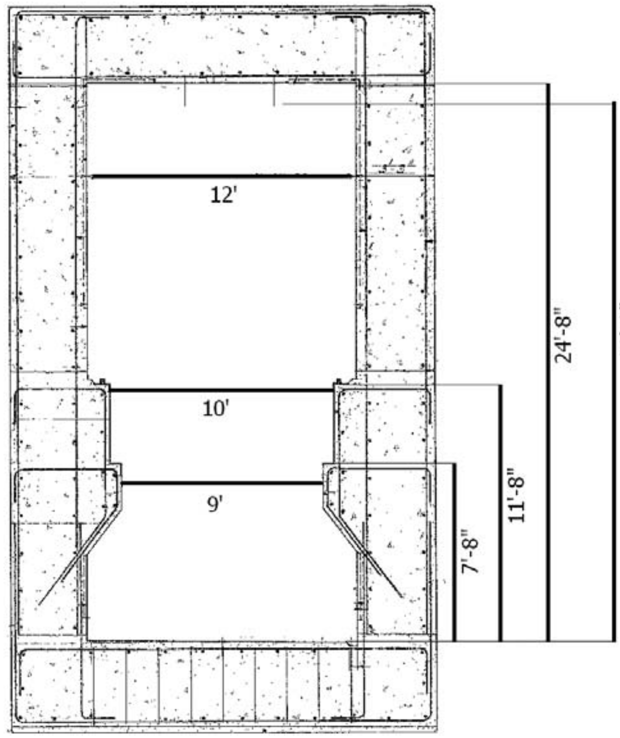


Figure 3: To the left, picture of the tunnel. To the right, the important dimensions of the tunnel. As can been seen, the cranes have the height of two feet. It was very important in the design to line up the crane with the center of gravity of the Klystron.

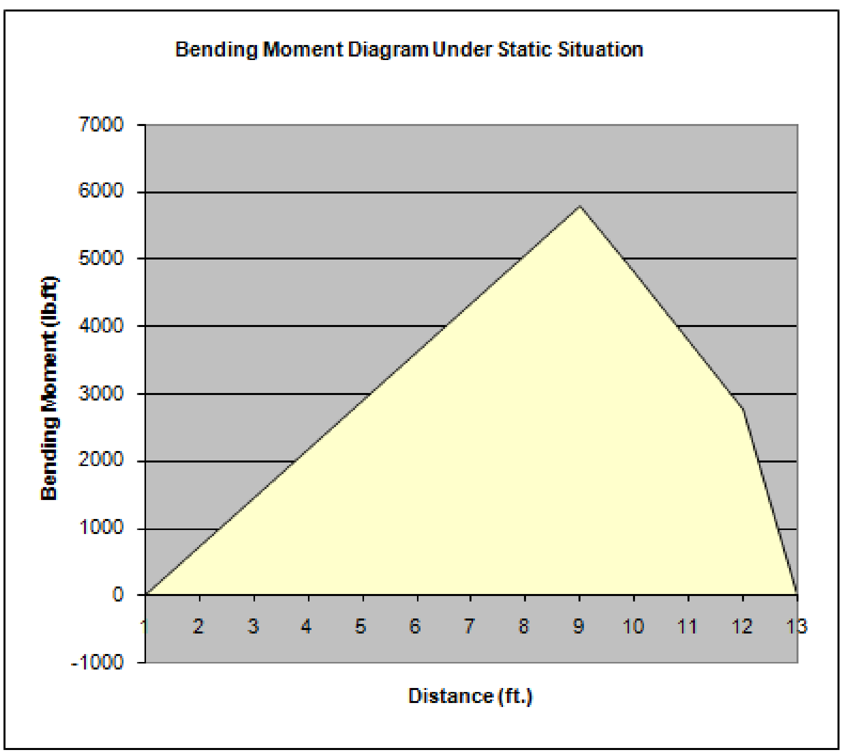


Figure 4: Bending Moment of the Beam under Static Load

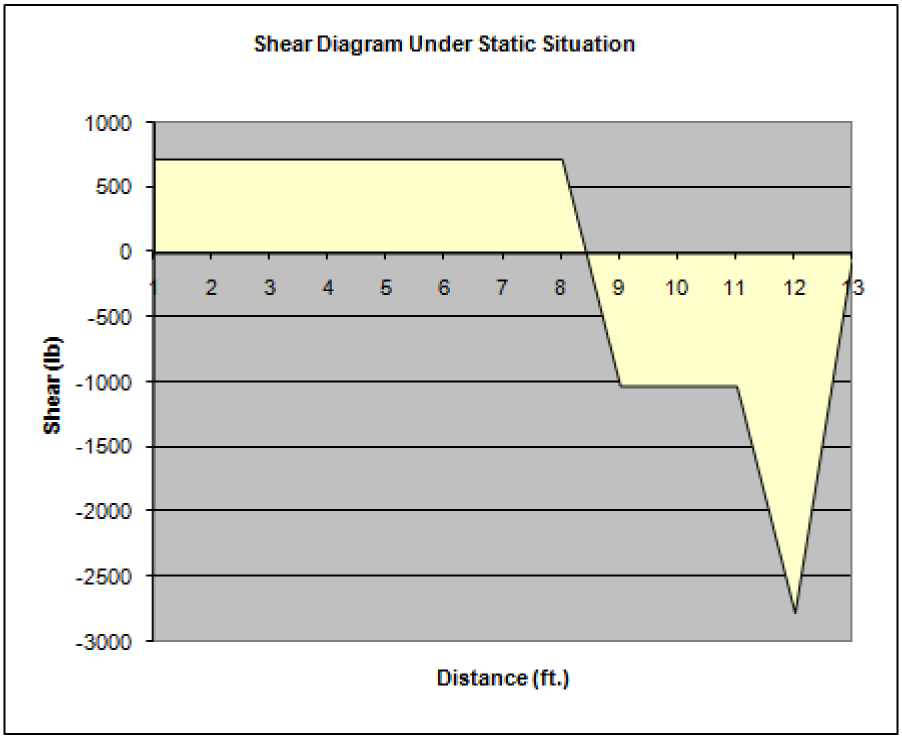


Figure 5: Applied Shear on the Beam under Static Load

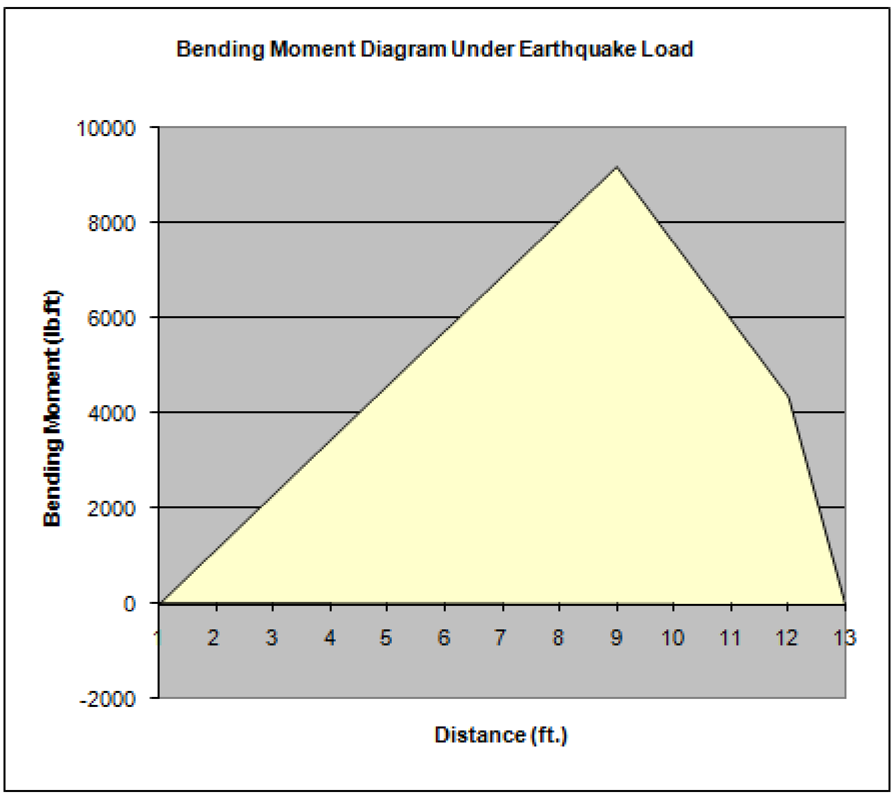


Figure 6: Bending Moment of the Beam under Earthquake Load

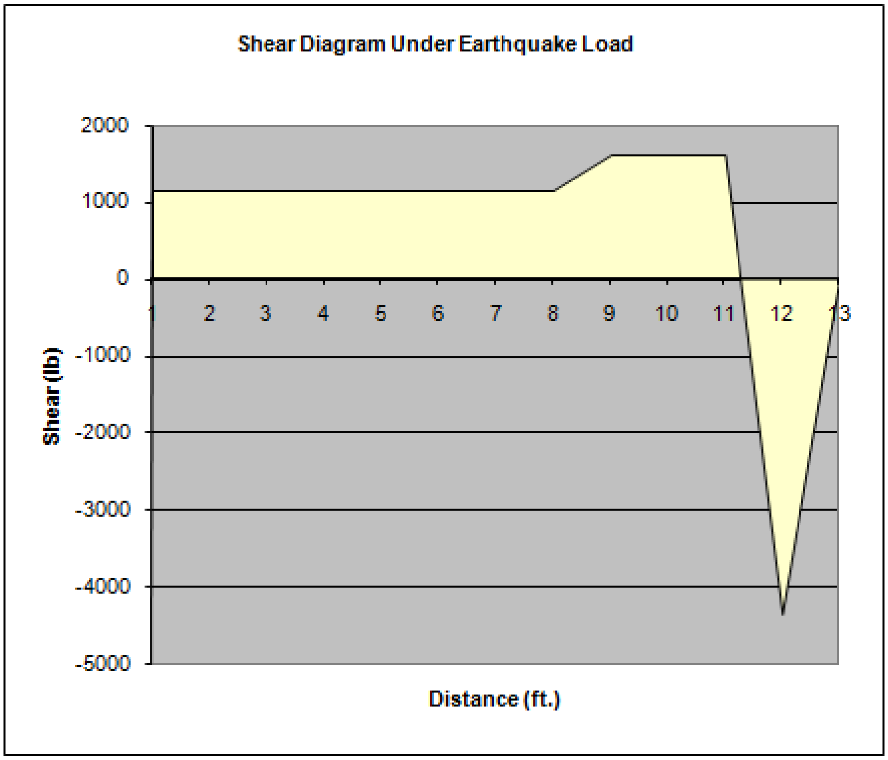


Figure 7: Applied Shear on the Beam under Earthquake Load

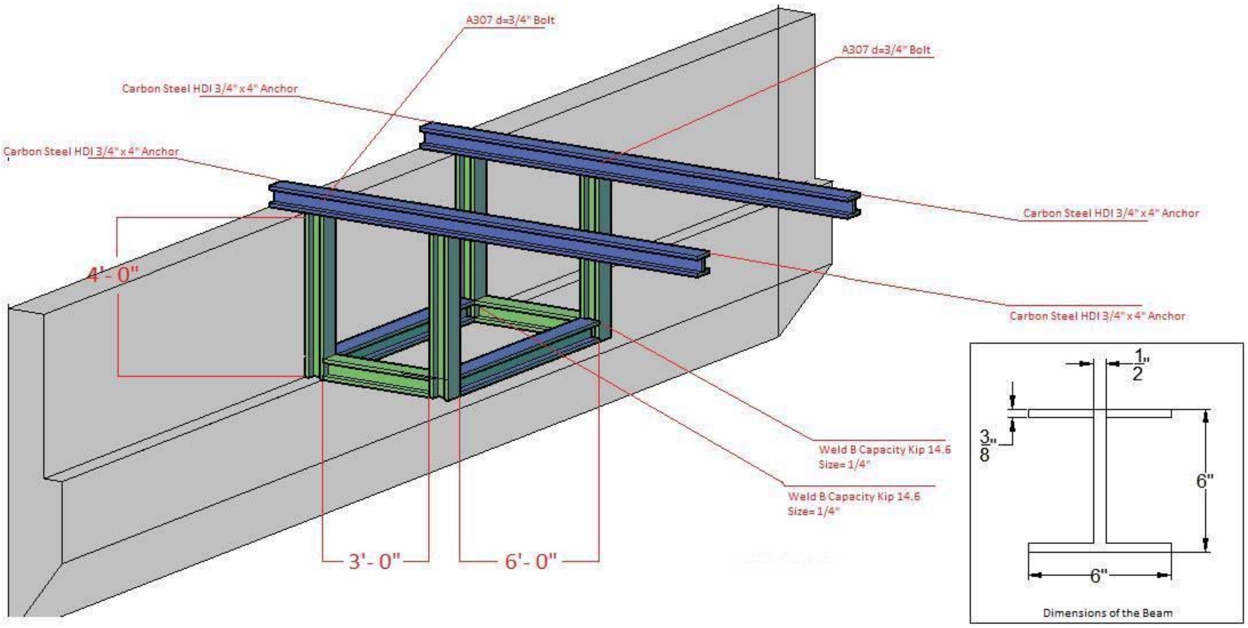


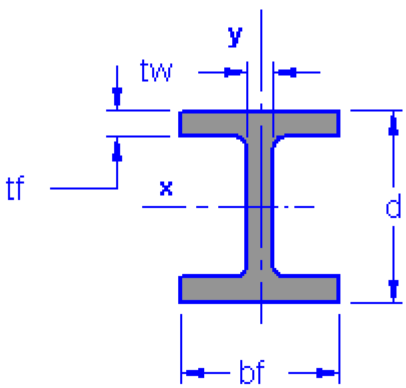
Figure 8: The final specification and dimensions for the Klystron cage hanging from the beam.

Calculation Chart for the Tunnel B Design

	Static	Earthquake
Total Load	6,000 lb	9,455 lb
Reactions of Main Beam (vert.)	729 lb & 2771 lb	1,149 lb & 4,366 lb
Maximum Bending Moment	5800 lbf	9192 lbf
Maximum Shear	2,771 lb	4,366 lb
Bending Moment @ Center	4,374 lbf	6,894 lbf
Shear @ Center	729 lb	1,149 lb
Base Shear (V)	4,200 lbf	4,200 lbf
Horizontal Seismic Force (E_h)	---------------	5,460 lbf
Lateral Seismic Force	---------------	6,618.5 lbf
Torsion Moment	25,200 in-lbf	39,711 in-lbf
Stress @ Load	5703 PSI	8,987 PSI
Load on Each Frame Connected to the Heavy Main Beam	1750 lb	2757.5 lb
Overall Load on a Frame Connected to the Heavy Beam	3500 lb	5515 lb
Seismic Loading on Elements of Structures	-------------	10,125 lbf
Building Period	------------	.398 s
ignore this option Bolt to hold Beam-Beam Connections	A307 d=3/4” Angle Thickness t=1/4” Resist 17.7 kip	A307 d=3/4” Angle Thickness t=1/4” Resist 17.7 kip

Weld to hold Beam-Beam Connections	Weld B Capacity kip 14.6 Size= ¼"	Weld B Capacity kip 14.6 Size= ¼"
Beam Resisting Base Shear	----------------	4 anchors (one at each end of the 2 main beams holding the machine) 4x(Carbon Steel HDI ¾")
Overturning	----------------	Need to resist 165 lb.ft
Stiffness (K)	$\frac{48\ E\ I}{L^3}$ I= 41.4 in^4 L =12 ft. E=	Same for both
Natural Period Vibration (T)	-------------	$= 2\pi\sqrt{\frac{m}{g_c \times k}} = 2\pi\sqrt{\frac{9240\ lb}{\frac{32.2\ ft - lb}{lb - sec^2}}}$ ×

Table 1: Tunnel Calculations based on Static and Earthquake Loads.



iBeam	Description
Name	W6x20 iBeam
Dimensions	6" by 6"
X-Area (in^2)	5.87
d (in)	6.2
bf (in)	6.02
tf (in)	0.365
tw (in)	0.26
I_{xx} (in^4)	41.4
I_{yy} (in^4)	13.3

Table 2: Specification of the W6x20 iBeam