Hat Truss + Outrigger

Introduction

The design of an all braced core structure resulted in excessive drifts in the N-S direction necessitating alternative schemes to be researched to bring the overall drift to an acceptable level. The second structural redesign builds upon the optimized braced frame design; however rigid horizontal outriggers will be designed at roof-top mechanical levels to help limit the excessive drifts in the N-S direction. Design assumptions and goals will be made during the redesign to focus the study on mainly the N-S lateral system. The concept and behavior of horizontal outriggers and hat trusses will be discussed. The design results of the outrigger performance will be compared to the design criteria and conclusions will be made.

Methodology

Outrigger trusses can be idealized as rigid horizontal trusses connected to a braced frame which acts like a restraining spring resisting the rotation of the braced frame. The behavior of a hat truss with rigid outriggers can be seen in Figure 6.8 below. As the braced core wants to rotate, as discussed previously, the outrigger virtually pulls the braced frame back to horizontal by introducing axial compression and tension in the exterior columns.

The outrigger connects the braced frame an exterior column effectively widening the "chords" of the vertical cantilevered truss discussed previously. By engaging exterior columns, located further way from the center-line of the frame, a greater resistance to overturning moments can be accomplished. Reviewing equation (6-3) from the Moment-Area method, assuming all columns are equal, the larger the distance from the center-line a column is, the greater the effective moment of inertia of the structure. A larger moment of inertia results in more efficient resistance to overturning moments and reduced drifts caused lower axial deformations.

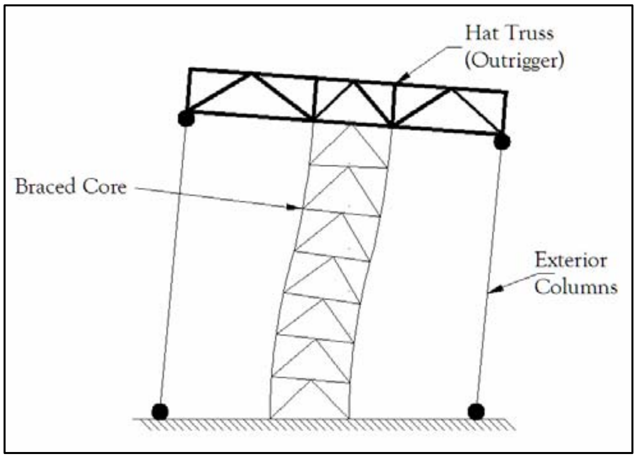

Figure 6.8: Hat Truss and Outrigger Behavior

To engage all exterior columns together, instead of just the outrigger connected columns, a perimeter truss is used to "tie" together all columns. A perimeter truss located at the top of the structure is classified as a "hat" or "cap" truss while trusses located in other locations can be called "belt" trusses. The efficiency of this type of system is found in the minimal amount of extra steel required to cause a substantial drift reduction.

Assumptions and Design Goals

To effectively evaluate the validity of the hat truss and outrigger system many factors and limiting assumptions must be made. Assumptions made in the design of the hat truss and outrigger system and the goals which are to be accomplished are as follows:

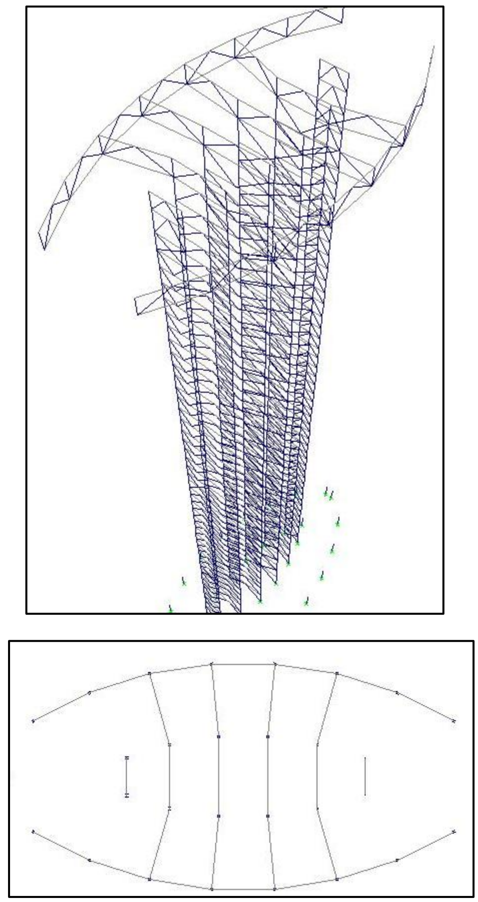

Figure 6-9a,b: (a) Hat Truss, Outrigger and Core Geometry (ETABS); (b) Hat Truss and Outrigger Plan view: Outriggers on BF #2, #3, #4 and #5 (from left to right)

Assumptions:

1. The optimized braced frame design shall be used as the core structure.
2. Members shall be redesigned if insufficient after incorporation of the hat truss and outrigger system.
3. Only the N-S direction will be analyzed in this study.
4. Outriggers will be designed for BF #2, #3, #4 and #5.
5. Calculated ASCE 7-02 wind loads control the strength of N-S frames. See Appendix A.
6. Limiting slenderness ratios for braces: Tension KL/r <= 300 Compression <=200.
7. P-Delta effects shall be accounted for in deflection and strength design.
8. Mechanical equipment can be moved without significant impacts on the building.

Design Goals:

1. Design an efficient and least weight alternative to a reinforced core.
2. Further reduce inter-story and total drift to H/480 in N-S direction by use of outrigger and hat truss systems.
3. Minimize impact on interior spaces and layouts by placing outriggers in mechanical plant spaces.
4. Design outriggers for use in further structural studies.

Design Process

The design of the hat truss and outrigger system starts with using the optimized braced frame design. The member proportions remain the same through the height of the structure; however, outrigger trusses and a hat truss are designed to help resist the rotation of the braced core.

The design of the outrigger truss assumes the outriggers are infinitely rigid and the axial elongation and shortening of the exterior columns is equal to the rotation of the core, times the column distances from the centerline of the frame. If the distance of the equivalent column is d/2 from the center and θ is the rotation of the braced frame, the axial forces and deformations in the exterior columns is equal to θd/2. An equivalent spring stiffness can be calculated for a unit rotation (θ=1) which results in the exterior column deformation being equal to 1xd/2=d/2 units. The axial load in the equivalent columns can then be found by equation (6-9) below. The rotational stiffness of the cap truss, K, is then given by the axial load in the equivalent columns times the distance from the centerline of the frame. The restoring couple, or the rotational stiffness, can then be found by equation (6-10).

$$P = \frac{AEd}{2L} \quad \text{(6-9)}$$

$$K = P \times \frac{d}{2} \times 2columns$$

$$K = Pd \qquad \text{(6-10)}$$

$$K = \frac{A_i E d^2}{2L}$$

The amount of reduction in drift depends upon the rotational stiffness and magnitude of the rotation of the braced frame at the top. The outriggers are designed to apply a 50kip load on the exterior columns. The resulting design typical of all outriggers can be seen in Figure 6.10 below. The members were checked against the interaction equations of (H1-1a) and (H1-1b). Outrigger truss members for BF #2 were checked for combined loading. The combined force ratios seen in Figure 6.11 are under unity and therefore satisfy the strength design the braced outrigger design.

The extra axial force caused by the outriggers caused a slight increase in some upper level columns to meet strength requirements. The original steel tonnage for the braced core is 19095 tons. After the column sizes were adjusted the resulting hat truss tonnage is 20210 tons, an increase of almost 5.5%. The resulting deflection results can be seen in Table 6.4.

Figure 6.10: Framing Member Design (BF #2)

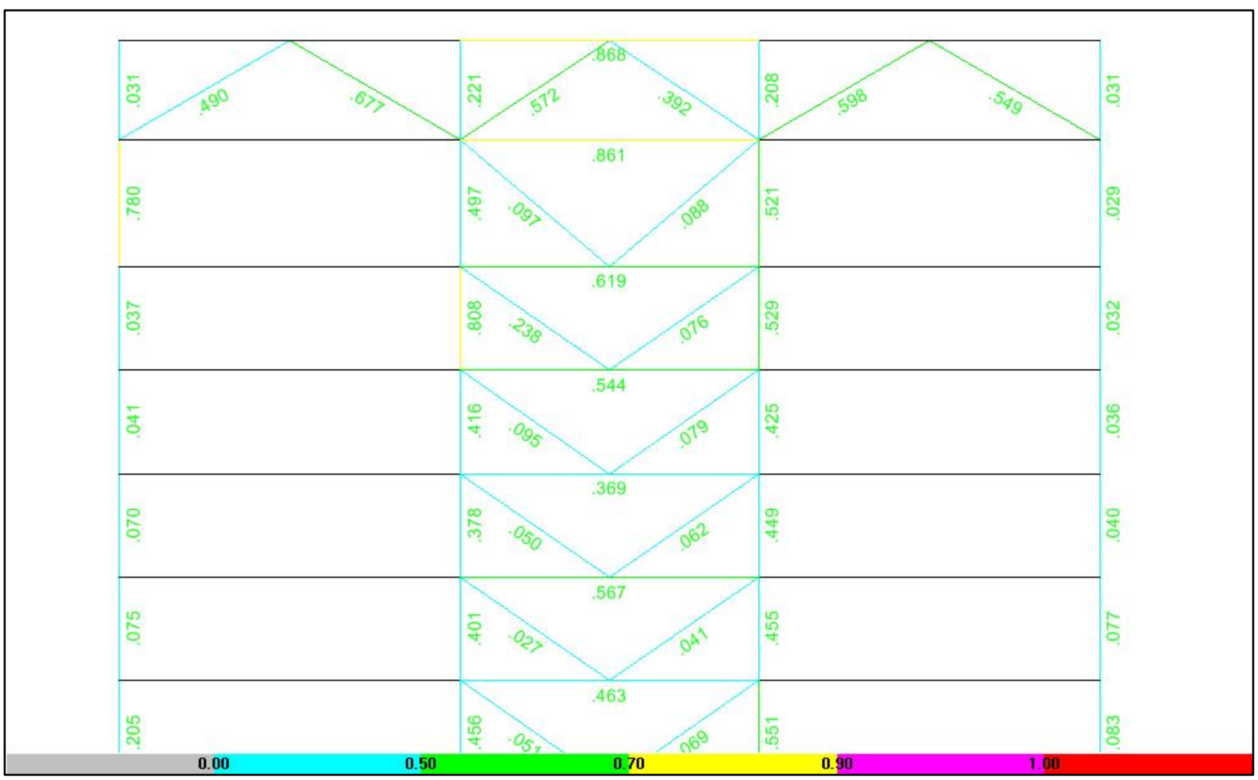

Figure 6.11: P-M Member Ratios BF #3 (Limit =1.0)

Hat + Outrigger Drifts		No P-Delta			Including P-Delta Effects		
	Load	**UX**	**UY**	**RZ**	**UX**	**UY**	**RZ**
N-S	WINDY	0.177	25.8747	0.00037	0.1937	27.0335	-0.00039
	TUNNELNS	0.1041	15.2706	-0.00024	0.1137	15.9389	-0.00025
	EQY	0.319	18.7338	-0.00422	0.3473	19.5378	0.00444
	H/480		**17.0825**			**17.0825**	
E-W	WINDX	8.7577	0.0838	0.0004	9.084	0.1103	0.00046
	TUNNELEW	2.9926	0.026	0.00016	3.0997	0.0348	0.00018
	EQX	18.7556	0.1714	-0.00095	18.3448	0.2229	-0.00099
	H/1000	**8.1996**			**8.1996**		

Table 6.4: Hat Truss + Outrigger Total Drift (inches)

Results

For the Hyatt Center, the 4 concentrically braced frames in the N-S with outrigger trusses and hat trusses connecting the exterior columns proved to help lower the top drift of the building resulting in drifts lower than the H/480 and H/1000 in the N-S and E-W directions respectively. Some upper level exterior columns had to be redesigned for the increased axial load caused by the resisting couple in the outriggers. The additional steel tonnage from the outriggers and increased column sizes is very minor, approximately 1115 tons, resulting in a drift reduction of 9-inches. The ratios of braced frame drift (24") to the Hat Truss drift (16") is a 1/3 decrease in drift with only a 5.5% increase in steel tonnage. This proves that a hat truss is efficient in lowering overall drifts in a building when placed at the top of a structure.

As seen in Table 6.4 above, the E-W braced frames are meet allowable drift limit of L/1000 set by the structural engineer on the project when checked with the wind tunnel analysis data. The N-S braced frames meet the allowable drift limit of H/480, however, varies by only 1". Although the building drift is acceptable, considerations like cracking of interior partitions, cladding movements and other interior settlement issues should be taken into consideration. To have an acceptable design, the overall drift should be lower than the allowable to reduce the chance of unsightly partition cracking and excessive cladding movement which could develop assembly performance issues later in service.

An investigation into adding more outriggers in the N-S direction will be required to further reduce the N-S drift. The positive results a hat truss and outriggers at the roof levels to the building drift performance was ultimately demonstrated. Therefore, further reduction can possibly occur by resisting the braced frame rotation with outriggers lower in the building instead of relying on just one outrigger system at the roof. The combination of 2 outrigger systems and "belt" trusses in mechanical levels may prove to reduce the overall drift.