CABLE BRACING SYSTEM FOR TALL BUILDINGS

M. A. Saleem

Department of Civil Engineering, University of Engineering and Technology Lahore
Corresponding Author E-mail: msale005@fiu.edu

ABSTRACT: Selection of wind force resisting system is an important decision in the design of tall buildings, especially for those located in hurricane prone regions. Rigid frames, shear walls, braced frames, framed tube, bundled tube and hybrid system are the common structural forms used to resist lateral forces produced due to wind. Cables have a great potential to be used as a structural element. Cable stayed and hanging bridges and guyed towers are the common structural applications of cables. Not much work has been done to use cables for bracing tall buildings against the lateral movement produced by natural forces like wind and earthquakes. This research work proposes an external cable bracing system for tall buildings which may be used in the future for high-rise structures. A sixty story tall building has been analyzed for the wind speed recommended for Miami, FL., USA., using a shear wall bracing system and the proposed cable bracing system. Comparison of structural performance of the two systems is presented to establish the suitability of the cable bracing system as a part of the wind force resisting system.

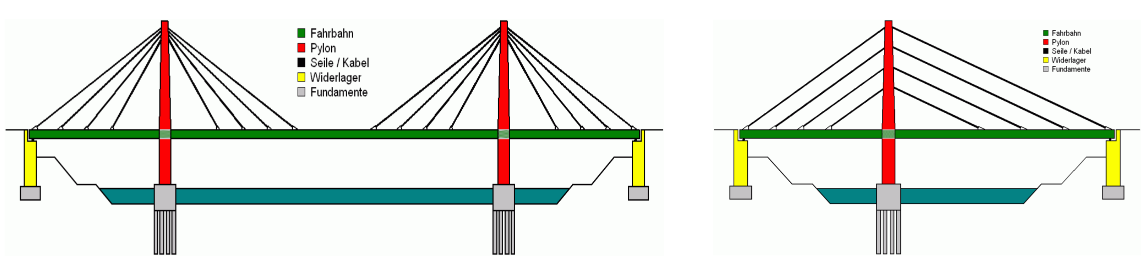
Key words: *Bracing system, Cable, Lateral Displacement, Tall Buildings, Wind Loads.*

INTRODUCTION

Structural design of tall buildings for lateral forces is usually governed by stiffness criteria rather than strength criteria[1]. The performance is evaluated in terms of inter-story drifts, maximum lateral displacements, economic considerations and material usage[2]. In general, as one of the representative indices of stiffness design, the maximum lateral displacement at the top of high-rise building is checked not to exceed a specified limit proportional to the building height. Although the limit on the maximum lateral displacement of a high-rise building subjected to wind loads is not provided as a standard, it is usually designed and implemented in construction to be in the range of 1/400-1/600 of the building height[3]. Excessive lateral movement can cause structural and non-structural damages, and also make the occupants uncomfortable. Various structural systems have been developed over the years which include, but are not limited to rigid frame system, braced framed system, shear wall system, framed tube system, wall framed system, bundled tube system and hybrid systems, which are combinations of different structural forms[4].

In this study, a sixty story tall building has been analyzed using the shear wall system, and a combination of shear walls and cables on the external faces. The idea is to replace the exterior shear walls with cables. Cables on the exterior face contribute in reducing the lateral movement under the wind forces, increase the usable space and may also serve as an architectural element on the facade. Cables have been frequently used in bridges but their use in tall buildings has been limited. The structure is analyzed for a wind speed of 146 mph which is recommended wind speed for Miami by the Florida Building Code.

Inspiration: The inspiration for using cable bracing comes from the cable stayed bridges. Cables have a great potential to support large loads effectively. The arrangement of cables used in this research is similar to the harped arrangement of cables in cable stayed bridges. In bridges, the cables support horizontal surfaces (slab decks) and mainly resist gravity loads, whereas, in buildings, cables support the vertical members and control the lateral displacements. Figure 1 shows the harped and fan arrangement of cables in cable stayed bridges.



(Fan Arrangement) (Harped Arrangement)

Figure 1: Arrangement of Cables in Cable Stayed Bridges

Description of Structures: The size of the structure is 100' x 100' x 720' with five bays in both directions, 20' x 20' each. The total number of stories are sixty with each story having a ceiling height of 12'. Stories and height of the structure are selected to make it behave as flexible. A structure having natural frequency less than one is considered flexible. Figure 2 shows the basic layout of the structure without shear walls and cables.

Following are the attributes of structure:

f_c' = 5000 psi
f_y = 60,000 psi (for reinforcing steel)
f_y = 250 ksi (for cables)
E_c = 4030 ksi
E_s = 29,000 ksi (for reinforcing steel)
E_s = 24,000 ksi (for cables)
Final area of one cable = 7.5 in^2
All slabs thickness = 6 in
All columns = 24 in x 24 in
All beams = 9 in x 18 in

Following approximate natural frequency (f) of structure was used to find the initial wind gust factor:

$$f = \frac{10}{No.\ of\ \ Stories} = \frac{10}{60} = 0.167\ hz$$

Structural engineers in Miami generally use a drift index of 1/400 for tall buildings. Therefore, for a height of 720 ft the allowable lateral displacement at the top becomes 21.6 in. The inter-story drift should be limited to 0.015h, where h is the story height[5]. For 12 ft story height the allowable inter-story drift becomes 2.16 in.

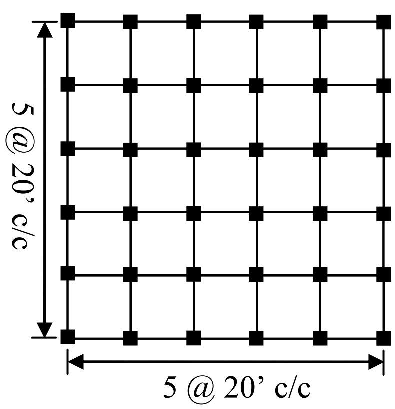


Figure 2: Basic Layout of Structure

Analytical Work: Dynamic analysis of the structure has been performed using SAP 2000, a general purpose finite element program. The horizontal stiffness was assumed as infinity using the diaphragm option of the programs. Due to the limitation of computer memory, and the symmetry of loading and the geometry, the structure has been analyzed only for positive x-direction wind (left to right). The primary objective of analysis was to evaluate the response of the structure against wind forces produced by 146 mph wind. ASCE 7-05[6] is used for the calculations of wind forces.

In the first place, the structure was analyzed with the rigid frame structural system as shown in figure 2. Shear walls were than introduced step by step to control the lateral displacement. Thickness, length and location of shear walls were altered successively to reach the most suitable configuration which could bring the maximum lateral displacement within the allowable limit (21.6 in). Figure 3 shows the final configuration of shear walls, which satisfies the lateral displacement and inter-story drift limits for the x-direction wind.

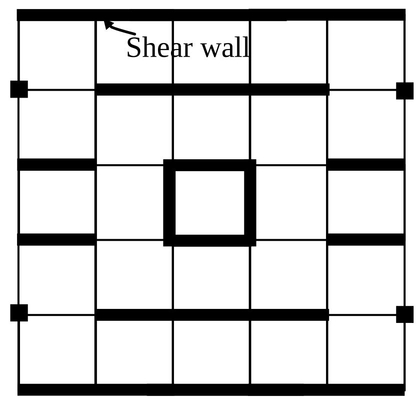


Figure 3: Final Arrangement of Shear Walls

Finally, cables were introduced on the exterior face to replace the shear walls. Different arrangements, sizes and inclinations of cables were used to finally reach the configuration of cables shown in figure 5. Square shear wall tubes (8' x 8') were introduced at the corners to provide strong support to the cables. A group of every six floors is tied down at a common point on the floor. Figures 4 and 5 present the structural scheme and arrangement of cables.

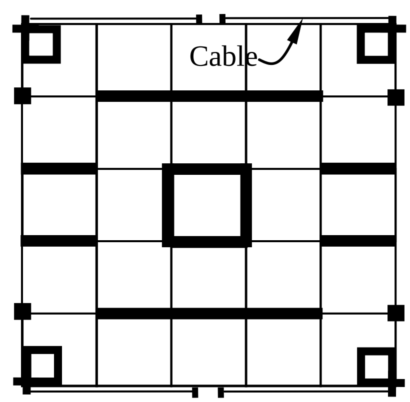


Figure 4: Structural Scheme with Cables

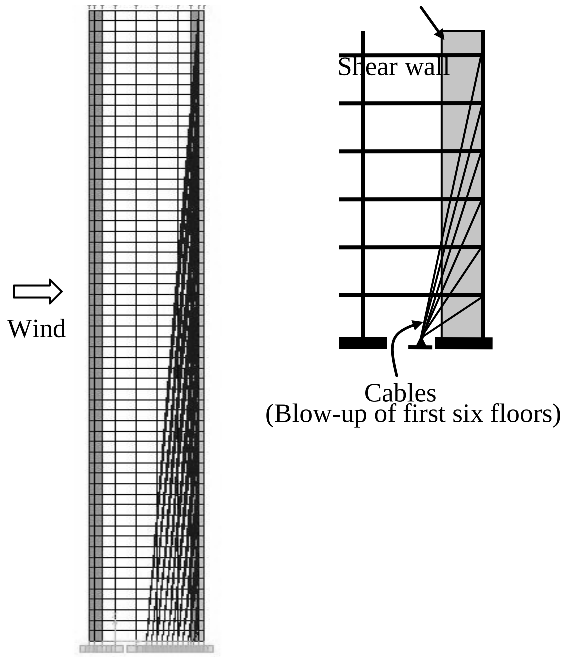
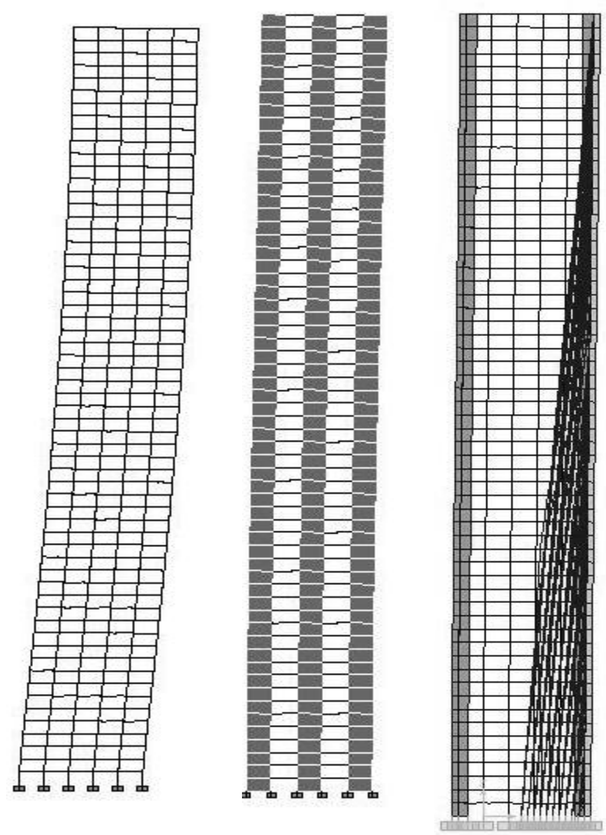


Figure 5: Arrangement of Cables

Table 1: Results Summary of Three Structural Systems

Structural System	Maximum Displacement (in)	Maximum Inter-Story Drift (in)
Rigid Frame (Beam-Column)	269.13	6.80
Shear Walls	20.56	0.439
Shear Walls with Cables	20.90	0.500

Maximum lateral displacements at the top of the structure, and the maximum inter-story drift for the three structural systems are summarized in table 1. From table 1, it can be concluded that the lateral displacement and the inter-story drifts are effectively controlled by the shear wall-cable bracing system. Figure 6 shows the deformed shapes of three systems. Figures 7 and 8 show the distribution of lateral displacements and inter-story drifts of the three structural systems.



(a) (b) (c)

Figure 6: Deformed Shapes of Three Systems: (a) Rigid Frame System;
(b) Shear Wall System; and (c) Cable Bracing System

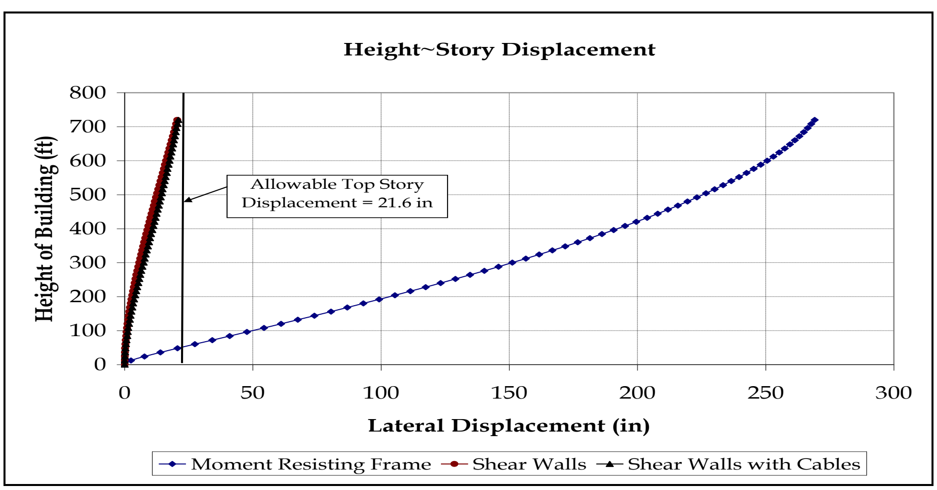


Figure 7: Distribution of Lateral Displacement

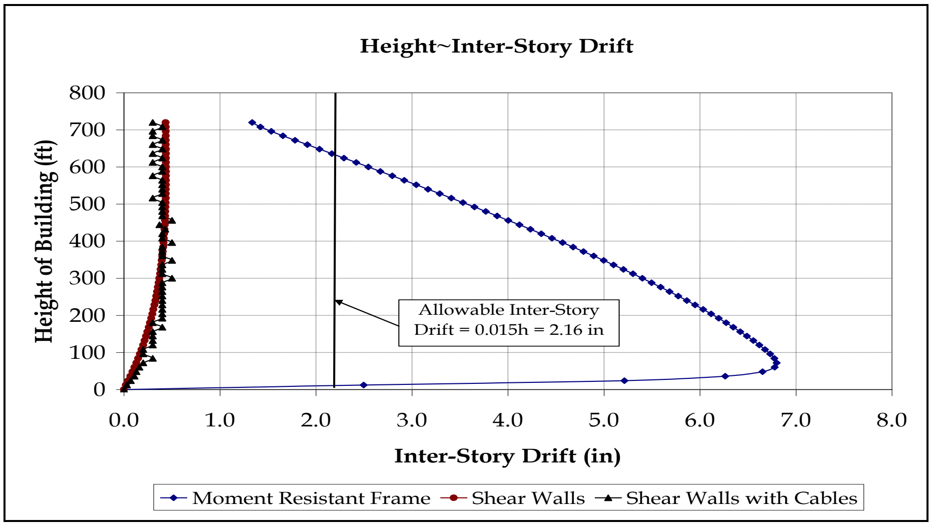


Figure 8: Distribution of Inter-story Drift

Conclusions: In the light of this study, the following conclusions can be drawn:

- From the distribution of the lateral displacement and inter-story drift it is demonstrated that cables along with shear walls can effectively control the lateral movement of the structure produced by the wind forces.
- Replacing shear walls with cables not only reduces the construction time but also increases the useable space. Cables may also serve as an architectural element on the facade.
- The cable bracing system can be more effective for the buildings with a smaller H/B ratio (H is height and B is width of the building). With a smaller H/B ratio, cables will have lesser slope, thus will be more effective to resist lateral forces.
- One general observation is that a shear walls-cable system has lesser computational requirements than an all-shear wall system.

Recommendations for Future Research: The following are the important aspects deserving further investigation:

- Effect of creep, relaxation and temperature forces on the long term performance of cable bracing;
- Analysis of cable for vibration;
- Impact of Prestressing on effectiveness of cables;
- Collapse analysis of the structure with cable bracing;
- Economic comparison with other structural systems; and
- Wind tunnel testing to validate the theory.

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