SEISMIC BRACING OF A DISTRIBUTED CABLE TRAY SYSTEM

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ABSTRACT :

A large telecommunications company built a series of facilities in the Seattle, Washington area. The facilities included large rooms containing cabinets of electronic equipment. A series of cable trays in multiple layers were installed above the equipment rack to provide cabling for the equipment. The cable tray system represented a large distributed mass that was supported between the top of the equipment cabinets and the roof framing. An innovative bracing system was designed to provide lateral bracing for the cable tray system. The bracing system was designed to meet building code requirements in addition to the owner's design criteria. Recommendations are made for improvements in the design procedures for seismic bracing of nonstructural components.

KEYWORDS: Nonstructural Bracing Cable Tray Design

1. INTRODUCTION

A large telecommunication company embarked on a program that included building a series of telecommunications facilities in the Seattle, Washington area. Each of these facilities included a room with a large number of telecommunications equipment cabinets. Above these cabinets, are cable trays that provide power and communications cabling to the cabinets. Since the facilities were located in a area of high seismicity, the cable tray system was required to be braced to resist seismic forces. In addition, the owner of the facility imposed additional design criteria for the seismic bracing. This criteria, known as Bellcore GR-1275-CORE, is a standard design criteria for telecommunications.

1.1. Building Description

The buildings that housed the telecommunications equipment were generally new, one-story buildings constructed with concrete block masonry walls. The concrete block masonry walls are reinforced and fully grouted. The roof framing consisted of open-web steel trusses supporting a metal deck roof with a thin concrete topping slab. The first floor was constructed with a concrete slab supported on grade. An exterior view of a typical building is shown in Figure 1.

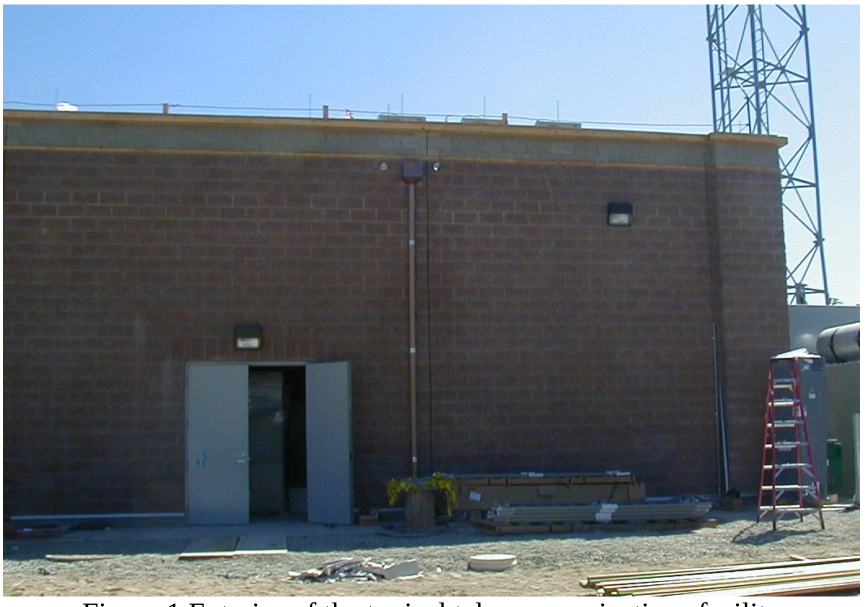

Figure 1 Exterior of the typical telecommunications facility

The telecommunications equipment cabinets within the facilities are standard steel proprietary cabinets arranged in rows. The cabinets are about 1.9 meters (6 feet) tall and filled with various electrical components, as shown in Figure 2.

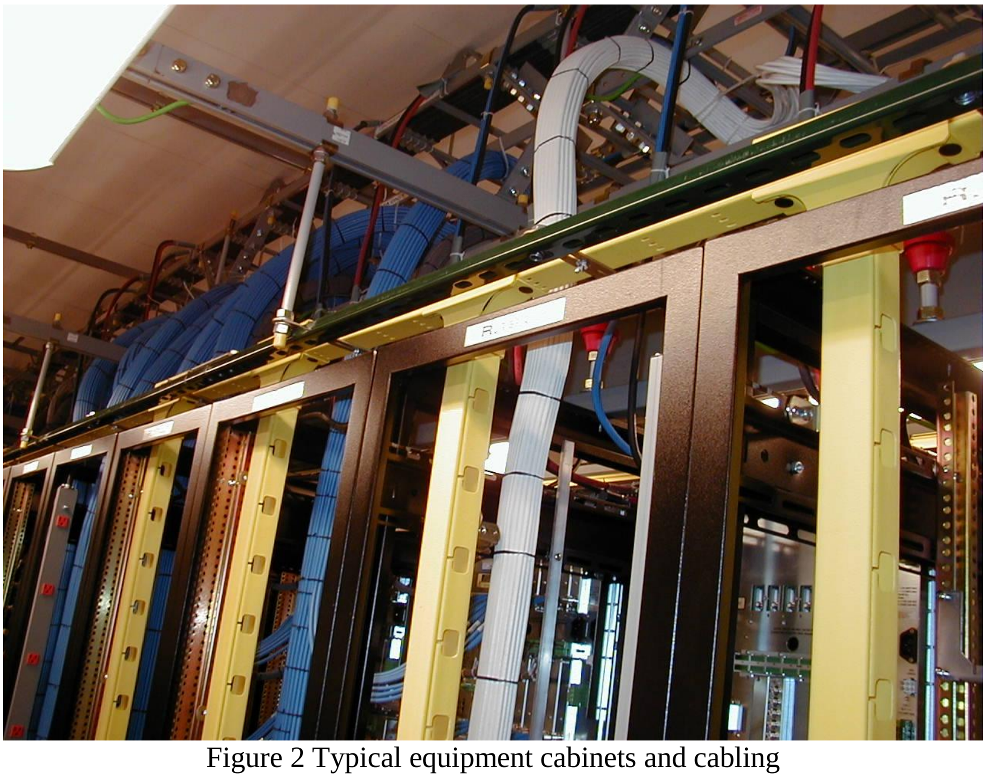

Figure 2 Typical equipment cabinets and cabling

Above the rows of equipment cabinets are three layers of cable trays supported vertically by regularly-spaced rows of proprietary steel channels at the top and bottom cable tray levels that are supported from the equipment cabinets with steel threaded rods, as shown in Figure 3. The widths of the cable trays varied from 0.5 meters (20 inches) to 0.9 meters (36 inches). The two or three layers of cable trays are interconnected with steel framing. These cable trays support various types of cabling that feeds from locations in other portions of the building to and from the equipment cabinets. These cable trays are constructed using prefabricated steel sections in a ladder-type configuration with solid steel longitudinal elements and light steel transverse “rungs.” These cable trays are assembled on site and the cable tray sections are spliced together using bolted connections. The cable trays have diagonal bracing between layers of cable trays in the longitudinal direction using proprietary steel members and connected using bolts and clamps. The initial layout and design of the facilities did not account for lateral bracing of the cable trays.

The equipment cabinets were designed to support the equipment located within the cabinets. Since the telecommunications facilities were located in areas of high seismicity, heavy duty cabinets that were rated for seismic loading were used. Although seismically rated, the cabinets were not designed to resist the lateral forces associated with the cable tray system supported above the cabinets.

Figure 3 Typical configuration of layers of cable trays supported on proprietary steel channels

1.2 Design Criteria

The seismic bracing system was required to be designed to the requirements for nonstructural seismic bracing of the 1994 Uniform Building Code (UBC). The seismicity of the area was considered to be zone 3 as prescribed by the UBC. The Bellcore design criteria, which was also applied, required that the bracing of the cable trays could not rely on an attachment to the exterior walls or roof of the building.

2. DESIGN CONSIDERATIONS

The weight of the cables supported by the cable trays was a critical component of the seismic design of the cable tray bracing system. The electrical engineering consultants for the project provided a layout of the size and types of cables that would be supported on each level of the cable trays system throughout the facility. In many areas, the anticipated weights used for design were based on the maximum number of cables that could fit on the cable trays in anticipation that future expansion or reconfiguration of the system may result in loads that would exceed the original configuration. The typical loads on a cable tray level varied from 30 kg per meter (20 pounds per foot) to 375 kg per meter (250 pounds per foot) and there are typically eight to ten rows of cable trays. Thus the total weight of cables and cable trays for a facility exceeded 110,000 kg (240,000 pounds) over an area of about 230 square meters (2500 square feet). A typical layout of the cable trays is shown in Figure 4.

The construction of the cable tray system relied on proprietary cable tray elements. These elements had not been evaluated specifically for acting as structural elements to resist lateral earthquake forces. Thus, these elements could not be relied upon to resist substantial seismic forces.

Another important consideration in the design of the system was the requirement to avoid connecting any lateral bracing elements to the exterior walls or roof of the building. While this criterion initially seemed to be unnecessarily complicating, analysis of the walls revealed that the walls did not have the necessary flexural capacity to resist the out-of-plane lateral loads associated with the cable tray system and strengthening the walls would be more costly than providing an independent bracing system for the cable tray system.

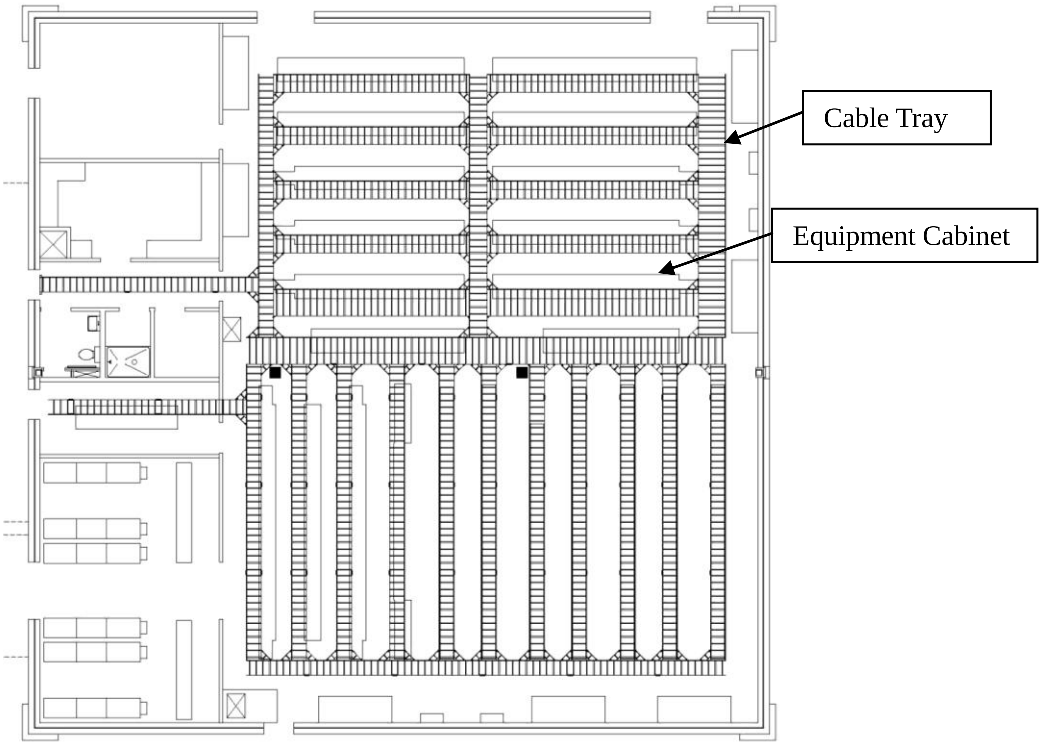

Figure 4 Typical layout on one layer of cable trays

A bracing concept relying on elements attached to the floor slab was proposed by the owner. This concept proved to be impractical since it would have either required large foundations for resisting overturning or diagonal bracing that would have interfered with operations because the braces would have been located in the aisles between the equipment cabinets.

After discussions with the owner and architect, the requirement to avoid connection to the roof framing was eliminated so that a bracing system could be designed using lateral support from the roof diaphragm. However, the construction of the roof diaphragm consisted of a metal deck with a thin concrete overlay. The total thickness of concrete above the metal deck was only 5 centimeters (2 inches). This provided a limited depth to install concrete anchors.

3. BRACING CONCEPT

The design concept used for the seismic bracing of the cable trays relied on a number of different structural elements of the lateral load path. The cable trays were treated as flexible bending elements in the transverse direction of the cable trays and rigid in the longitudinal direction.

The primary lateral force resisting elements were rectangular hollow structural sections (HSS) that span vertically from the floor to the roof framing and are located adjacent to the exterior walls on two orthogonal sides of the building. This allowed the HSS bracing elements to be partially concealed in the stud wall framing along the exterior walls and minimized the potential for disruption of operations that may be caused by the location of the structural elements in the facility. The vertical HSS bracing members were also offset from the exterior walls to allow the vertical bracing members to move laterally without impacting the exterior walls.

The HSS sections are attached to the proprietary channel sections at the upper and lower cable tray levels. Steel plates are attached to the HSS elements to which the proprietary channels are bolted, as shown in Figure 4. These channels were installed in pairs and arranged in a back-to-back configuration. The channels were placed in a regular grid in both directions and were spaced at about 1.5 to 1.8 meters (5 to 6 feet). The channels were spliced together with bolted connections using two 12 millimeters (1/2 inch) diameter bolts and were connected to the cable trays with clamps. These channels were relied upon as collectors to transfer the lateral forces from the cable trays to the primary lateral force resisting system in the longitudinal direction of the channels.

Figure 5 Typical HSS Bracing Members Attached to Proprietary Channels

The HSS bracing members were attached to the concrete floor slab using a typical steel base plate with typical post-installed anchors. At the top however, the connection was complicated by the thin concrete roof slab with the metal deck, which did not provide a substantial structural element to which to resist the lateral forces. Custom fabricated brackets were therefore designed to which anchors could be attached to the bottom of three roof deck flutes in order to spread the lateral forces. Two different types of brackets were used depending on the orientation of the deck flutes compared to the loading direction. One type of bracket is shown in Figure 6.

Figure 6 Custom brackets used to attach the top of the HSS bracing elements to the roof

The proprietary channels provided an effective method of transferring lateral forces from the upper and lower levels of cable trays to the HSS bracing elements, however the middle level of cable trays did not have a direct method of connecting the cable trays to the bracing elements. In the longitudinal direction of the cable trays, the three levels of cable trays were installed with regularly-spaced diagonal bracing, as shown in Figure 2. These braces were assumed to distribute the lateral forces from the middle level of cable trays equally to the upper and lower levels of cable trays. In the transverse direction of the cable trays the lateral forces from the middle level of cable trays were assumed to be transferred to the upper and lower cable tray levels using vertical steel rods that were installed to maintain vertical spacing between the levels. These threaded rods were checked in bending to transfer forces to the upper and lower cable tray levels.

4. SEISMIC FORCE ANALYSIS

Seismic forces for the cable trays, including the cable weights, were calculated using the nonstructural component seismic provisions of the 1994 UBC, which was the applicable design code in effect. The equipment cabinets were assumed to be independently supported and thus did not contribute to the lateral forces resisted by the cable tray bracing. Due to the critical nature of the facility, an importance factor of 1.5 was applied to the seismic forces. The calculated seismic forces coefficient (Fp) was 0.675 times the nonstructural weight.

For each facility, a seismic lateral force analysis was performed to determine the lateral forces being resisted by the HSS bracing elements. The tributary forces to each bracing element at the upper and lower levels of cable trays were based on the tributary weight along each row of channels acting as drag struts and assuming that the loads from the middle layer of cable trays were equally distributed to the upper and lower level of cable trays. The HSS bracing elements were then checked for the bending moments caused by the lateral forces. The connections at the top and the bottom of the HSS bracing elements were also checked for the reactions. The roof diaphragm was then checked for the additional lateral forces transferred from the HSS bracing elements.

The seismic bracing concept was based on the assumption that the bracing system acted independently from the seismic response of the building. To assess this assumption, a simplified model of the building and bracing system was analyzed using a finite element analysis to determine the periods of vibration of the building and the bracing system. The results of the analysis showed that the building structural framing, which consisted of stiff concrete masonry shear walls and a stiff roof diaphragm, had a substantially shorter period of vibration than the cable trays and their bracing. Thus, it was concluded that the response of the cable tray and bracing system would not be significantly affected by the dynamic response of the building and the design of the cable tray bracing did not need to account directly for interaction with the building response.

5. CONCLUSIONS AND RECOMMENDATIONS

The cable trays at the telecommunications facilities presented in this paper represent large masses located within the buildings. Traditional system for bracing cable trays using diagonal bracing extending up to the roof would have been impractical due to the extensive amount of cable trays, the lightweight framing of the roof, and the owner's initial criteria to avoid bracing attachments to the roof or exterior walls. An innovative bracing system was developed that utilized some of the existing cable tray framing elements and minimized the amount of new structural framing elements that needed to be installed, thus reducing the impact on the operations of the facility. The system design concept could be adapted to a variety of different cable tray layouts that were used in the various telecommunications facilities that the owner was building.

5.1 Building Code Design Implications

Bracing for many types of nonstructural components, such as cable trays, typically rely on diagonal bracing members. Often the bracing members are light steel framing elements. The use of bending elements, such as the bracing system used in these facilities is unusual. Current building code provisions for nonstructural bracing used in the United States follow the recommendations of ASCE 7-05. In these provisions, seismic forces for nonstructural components are calculated based on a response modification factor (Rp) that is related to the type of component being braced and does not directly consider the method of bracing. Thus the Rp factor is not directly related to the ductility or overstrength of the seismic bracing system for the nonstructural component. The vertical bracing elements used in this project behave in a very ductile manner as opposed to many bracing systems used for cable trays that rely on diagonal bracing. As with structural framing systems for buildings, the ductility of the bracing system for nonstructural components should be considered in determining the seismic design forces.

Current nonstructural design provisions implicitly consider that the behavior of the nonstructural components is affected by the dynamic behavior of the building. The design lateral force is based on the elevation at which the nonstructural component is attached to the building. In this project, the design lateral force would be amplified since the bracing is attached at the roof. Using the seismic bracing system developed for this project, the bracing is attached to the building at the roof, however because of the difference in dynamic characteristics of the building and the cable tray bracing system, the cable tray bracing system could be considered an independent structure even though it is attached to the roof of the building.

Seismic design of bracing for nonstructural components can become complex due to the configuration of the nonstructural components and the use of relatively light framing elements. Current building code design provisions treat many types of nonstructural components as "black boxes" that need to be anchored to the structural framing whereas the nonstructural components may be complex structures on their own. It would not be feasible for the building codes to address all of the types of nonstructural components and their bracing, the emphasis of the code should be on understanding the actual seismic response of the components and then applying appropriate design procedures based on the type of response rather than on the type of component.

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