SEISMIC DESIGN FOR HIGH-RISE STRUCTURES

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Abstract— In this study, the construction of high-rising buildings that lies within the geologically complex region of San Francisco, is investigated. After completing the geological research of the Bay area, for the seismicity testing, a model structure of 28 story building (The Orion Tower) is constructed from balsa wood which the woods are connected to each other by glue.

Keywords— Seismic design, Balsa wood, Columns, Structural-model, eccentric loading.

I. INTRODUCTION

The Bay area in California, is recognized as one of the most seismically active locations in the United States; the most powerful recorded earthquake occurred in the Bay Area part of the state many years ago. This study contents the design of building in order to serve as an icon of the city that celebrates modern engineering and architectural aesthetic and complements the breathtaking natural beauty for which this state is known. The purpose of the study is to construct a cost-effective structure that is designed for seismic loading as there is significant potential for future damaging earthquakes.

II. GEOLOGICAL RESEARCH

The Plan Project Area lies within the geologically complex region of San Francisco. The project area lies between the San Andreas and the Hayward Faults which is accustomed to Young bay mud zone. The Young Bay mud consists of thick deposits of soft, unconsolidated silty clay, which is saturated with water; these soil layers are situated at the bottom of certain estuaries, which are normally in temperate regions that have experienced cyclical glacial cycles.
Young Bay Mud underlies artificial fill in areas on which estuarine sediments were deposited and ranges in thickness from approximately 1 to 70 feet. The Young Bay Mud consists predominantly of high plasticity clay with minor layers of lean to sandy clay, silt to clayey silt, and clayey sand, with some peat interbred and lenses.
As a response to earthquake-induced ground shaking, lateral spreading occurs and is the movement of ground material toward a free face. Generally in soils, this movement is due to failure along a weak plane and may often be associated with liquefaction. In construction, soil is a significant part of the building process. If performed improperly, settlement of the soil could occur and result in unnecessary maintenance costs or structure failure. Almost all types of building sites and construction projects utilize mechanical compaction techniques. Whether you are working in peat, gravel, clay, silt, sand or loam soil, understanding the soil properties of your site help you make good construction decisions leading to success of the project. Construction on Young Bay Mud sites is difficult because of the soil's low shear strength, high compressibility and low permeability. In this geologically complex site, shallow foundations can be used for very lightweight buildings if there is a thick enough layer of non-bay-mud soil above the bay mud. But buildings which impose significant loads like ORION Tower, the structural loads should be transferred in safe to stiffer layers below the bay mud. Even with soil improvement, difficulties arise for shallow foundations because of consolidation, liquefaction and seismic densification risk. In San Francisco the most economical and safe foundation type for high rise buildings is deep foundations (Driven Precast, Pre stressed, Concrete piles). Deep foundations can be used where soft soil, non-engineered fill, or high groundwater level is present. (Fig 1)[1].

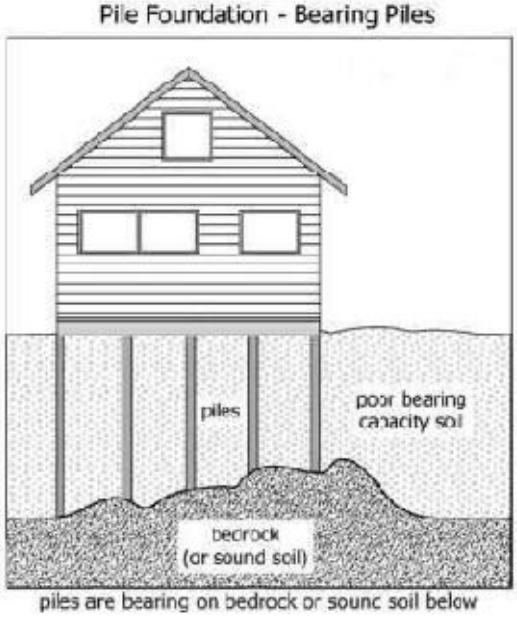


Figure 1: Deep Foundation

III. SEISMICITY

The San Francisco Bay Area is considered a region of high seismic activity with numerous active and

potentially active faults capable of producing significant seismic events. The U.S. Geological survey (USGS) Working Group on California Earthquake Probabilities has evaluated the probability of one or more earthquakes of Richter magnitude 6.7 or higher occurring in the San Francisco Bay Area, and concluded that there is currently a 62 percent likelihood of a magnitude 6.7 or higher earthquake occurring in the Bay Area by 2032. [2]

The San Andreas and the Hayward faults are the two faults considered to have the highest probabilities of causing a significant seismic event in the Bay Area. These two faults are classified as strike-slip-type fault and have experienced movement within the last 150 years .The San Andreas fault is a major structural feature in the region and forms a boundary between the North American and Pacific tectonic plates. Other principal faults capable of producing significant Bay Area ground shaking are listed in Table 1. A major seismic event on any of these active faults could cause significant ground shaking as was experienced during earthquakes in recent history, namely the 1868 Hayward earthquake, the 1906 San Francisco earthquake, and the 1989 Loma Prieta earthquake. The estimated magnitudes (moment) identified in Table 1 represent characteristic earthquake on particular faults.

IV. STRUCTURAL MODEL

Structural model is constructed of frame members and wall members that are attached to a structural model base plate with a structural model roof plate attached on top of the structural model. All frame and wall members are made of balsa wood.

V. ARCHITECTURAL DESCRIPTION OF THE STRUCTURAL MODEL

San Francisco looks like a sky when viewed from the hills at night and fascinated people with its unique landscape. Aforementioned situation of the city inspired me for the name of the Structural model, Orion Tower. Orion is a prominent constellation located on the celestial equater and visible throughout the world [3]. It is one of the most conspicuous and recognizable constellation in the night sky. So, it can be clearly said that the name of the Orion Tower matches the glint of the San Francisco city. Besides, the orion constellation gives its name to my project; its geomatrical shape has also inspired me for the architectural design of the tower. The longitudinal cross-section between the 15th and 25th floors of the building was designed according to the geomatric shape of the constellation (Fig. 2). The glass curtain-wall was designed to the facade of the tower to demonstrate the building and powerful. Also maximum area was used in the 15th floor, in order to serve more customers accompanied by the spectacular view of San Francisco.

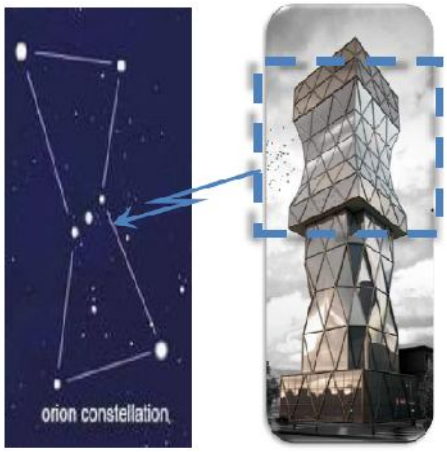


Figure 2: Inspiration

Table 1. Active Faults in the Bay Area. [2]

Fault	Recency of movement	Historical Seismicity	Maximum moment magnitude Earthquake (Mw)[3]
Hayward	1868_ Holocene	M6.8 1868 Many <M4.5	7.1
San Andreas	1989_ Holocene	M7.1 ,1989 M8.25,1906 M7.0,1838 Many <M6	7.9
Rodgers Creek	1969_Holocene	M6.7, 1898 M5.6,5.7, 1969	7.0
Concord-Green Valley	1955_Holocence	Historic active creep	6.9
Marsh-Creek Greenville	1980_Holocence	M5.6 , 1980	6.9
San Gregorlo-Hosgri	Holocence Late Quatemary	Many M3-6.4	7.3
West Napa	2000_Holocence	M5.2 , 2000	6.5
Maacama	Holocence	Historice active creep	7.1
Calaveras	1990_Holocence	M5.6-M6.4, 1861 M4 to M4.5 swarms 1970 , 1990	6.8

VI. STRUCTURAL DESCRIPTION OF THE STRUCTURAL MODEL

Although the framed systems are ductile, in the design of high-rise buildings, the framed systems alone do not provide enough rigidity or stability for the structure and shows shear dominated behavior under seismic actions [4]. After considering multiple variations of structural systems, framed systems with shear walls proved to be the most efficient choice with respect of lateral loads. It is a well-known fact that, framed systems have a good interaction with shear walls to insure rigidity and stability [5]. Structural elements were used symmetrical in plan and shear walls were placed at maximum distance from stiffness center in order to increase torsional rigidity (fig. 3). Furthermore, horizontal braces were used on the floor levels to distribute seismic forces to frames and shear walls and also to tie the structure together (Fig. 3).

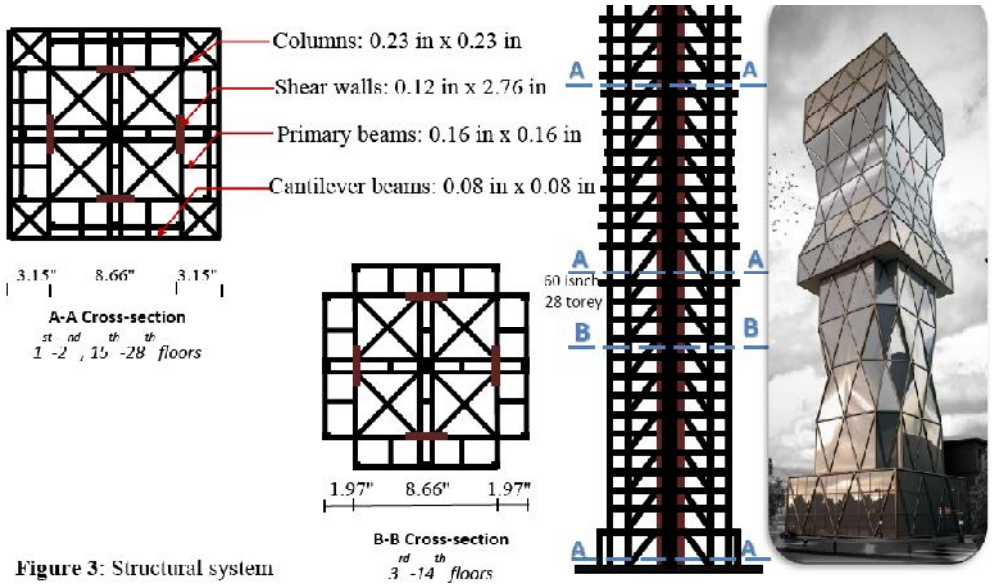


Figure 3: Structural system

VII. GROUND MOTION TESTING

The model building is subjected to three ground motions of increasing intensity which is named Ground Motion 1, Ground Motion 2, and Ground Motion 3. The structural response to all three motions is contributed to the annual seismic cost. The structure had to be tested on the University Consortium for Instructional Shake Tables (UCIST) (Fig. 4) unidirectional earthquake shake
table, with plan dimensions of 18.0 in by 18.0 in but due to the lake of economy I managed to make my own hand-made shake table by the support of my friends (Fig. 5).

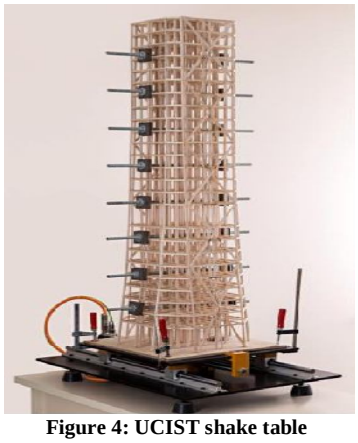


Figure 4: UCIST shake table



Figure 5: Hand-made shake table

VIII. PREDICTED STRUCTURAL BEHAVIOR

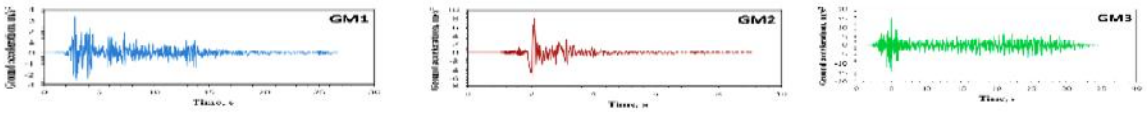
In order to evaluate the structural behavior of the system a time history analysis was performed with SAP2000 [6]. Furthermore, to improve structural model small scale structural tests have been done on shake table.
Performance Predictions Ground Motion Roof Drift, inch Roof Acceleration, g GM1 0.22 1.03 GM2 0.43 1.90 GM3 0.71 2.32 TIME HISTORY ANALYSIS Ground Ground Motions

TIME HISTORY ANALYSIS

Material Properties, (ASTM-C-365)	
Elasticity Modulus, MPa	3500
Poisson Ratio	0.4
Weight per Unit Volume, N	1099
Damping Ratio, %	10
Compression Strength, MPa	10.1
Tension Strength, MPa	9.4
Shear Strength, MPa	2

Ground Motions

Performance Predictions		
Ground Motion	Roof Drift, inch	Roof Acceleration, g
GM1	0.22	1.03
GM2	0.43	1.90
GM3	0.71	2.32



IX. CONSTRUCTION OF HAND-MADE SHAKE TABLE

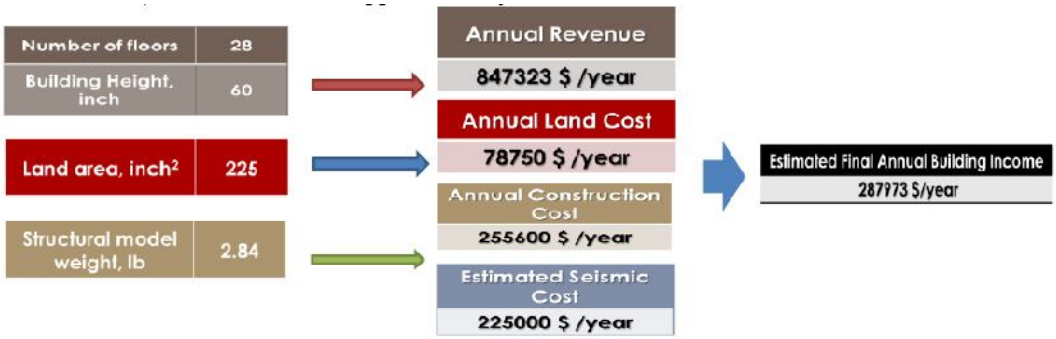
I used one bicycle, steel rod, chain, steel supports, wooden plates and rollers to produce this shaking table. Firstly I with the support of my friends, disassembled the bike and fixed the body of the bike by placing it on a steel support. Later, we used a chain and a steel rod to transmit the rotational movement of the pedal, to the wooden plate. Thus, we have ensured the wooden plate placed on rollers to move back and forth when the pedal turning. Then we tested the model using our shaking table and my friend's effort. It is clear that we can't get reliable and exact response values from this test. Because we can't give an exact seismic record to the model and also the response of the model is depending on the riders' effort (Fig. 6).



Figure 6: Construction of Hand-made shake table

X. ECONOMIC CONSIDERATIONS

Orion Tower is a 28 story building with a height of 60 inch. In the design the buildable area was used in the most productive way and 4998 inch2 rentable area was obtained. To maximize the final annual building income, maximum floor area was used at top and bottom floors. In addition to this, the Annual Building Cost is minimized by using a lightweight structure with using minimum number of materials, without ignoring the structural safety. Total weight of the building (Structural model) was calculated at approximately 2.2 lb.



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