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SEISMIC EVALUATION OF EQUIPMENT SUPPORTING STRUCTURES

M. B. Sharif, M. Ilyas, M. A Tahir[*],A.U. Qazi, S. Ahmed[**]

Department of Civil Engineering, University of Engineering and Technology, Lahore.
[*]Department of Architecture Engineering University of Engineering and Technology, Lahore.
[**]Sturcture Division, Saudi Consultants, Saudi Arabia
Corresponding author e-mail: burhansharif@uet.edu.pk

ABSTRACT: Industrial buildings are commonly subjected to forces induced by machine vibrations, earthquake and wind loads. There are number of equipments which have vibrating actions and at the same time tall enough to withstand the wind and earthquake forces. This study deals with the 37m high vessel supported on two storey RC frame. The structure was modeled using STAAD PRO 2007. Equivalent lateral forces for model structure were calculated according to seismic provisions for Lahore. The anchorage mechanism between vertical vessels and table top foundation is studied in detail for earthquake induced loading. Anchorage mechanism was designed on ductile failure of stud and bolt. This study revealed that seismic forces on equipment supporting structures are 20 to 30 % more than ordinary structures due to low lateral force resistance factor. Design of heavy equipment is primarily governed by large overturning moments. The tilting effect due to heavy equipment loads is catered by proper anchorages to ensure the safe performance under the severe earthquakes. The conclusions will also be useful for the structural designers involved in the design of such industrial buildings.

Key words: Equipment supported Structures, Vessels, Structures supporting machine.

INTRODUCTION

The Non structural components in a structure are not the integral part of the structure rather they are attached with the structure. Seismic evaluation of equipment supporting structure means to analyze the supporting structures for strong ground motion and to take the necessary remedial measures for structure, human life and property. According to Villarverd (1997) the non structural elements are also subjected to earthquake forces. Equipment supporting structure is designed such that it can release or absorb earthquake energy induced to the equipment mounted on it by the combined action of anchor, stiffness and damping etc. Supporting structures are affected due to the inertial loads and displacements caused by ground shaking, liquefaction and landslides. The functioning of non structural components is important for maintaining the functionality of the building. According to Taghavi and Mirinda (2003), the failure of non structural components may impart a huge loss. It was also reported by Scholl (1984) that failure of such structures causes huge financial implications other than their operational cost.

Adam *et al*. (2003) carried out the detailed investigation for two storey frame attached with a secondary element. He pushed the frame to elastic-plastic stage and determined the response of the secondary attached element. He found that experimental and numerical results are in close agreement to each other. However, the numerical results are dependent on the exact properties of the materials used in computations.

Equipment supporting structures are usually (braced/ unbraced, rigid/ pin connected) made up of concrete and steel. Supported equipments include horizontal and vertical vessels, heat exchangers, piping and miscellaneous mechanical and electrical equipments. Steel supporting structure utilizes moment resisting frame in one direction and braced frame in the other direction. Steel frame, braced in both directions are preferred if economical. To provide sufficient mass, stiffness and restrict vibration within permissible limit, concrete supporting structures are designer's first choice to support rotating equipments such as compressors, generators and turbines etc. because they provide sufficient mass, stiffness to restrict vibration within limits.

Equipments mounted at grade or installed on the upper levels of the structure fall in the category of nonstructural components. Nonstructural elements generally divided into architectural, mechanical, and electrical systems and equipments. Mechanical components and systems include boilers, fans, air conditioning equipments, elevators and escalators, tanks and pumps, as well as distributed systems such as HVAC (Heating, Ventilation, and Air Conditioning) ducts work and piping systems. Electrical components include transformers, panels, switchgears, conduits, and cable trays etc. Nonstructural components are supported vertically and laterally by a structural framework independent of the component itself. Safety of structure against tilting of equipments due to earthquake loading is achieved by providing adequate member sizes and anchorage mechanism.

Seismic evaluation of equipment supporting structures is a growing field. Equipment supporting structures are commonly found in oil and gas refineries. This research work deals particularly with those equipments and systems that are installed on the supporting structures e.g. vertical and horizontal vessels, heat exchanger etc. Poor performance of nonstructural components and equipments is the major contributor of damage during an earthquake. The cost of loss of operations of equipments can exceed the value of the supporting structure itself. The new International Building Code 2006 incorporates more stringent design requirements for nonstructural components, and buildings in compliance with greater earthquake risk tolerance.

MATERIALS AND METHODS

Following materials strength are used for strength calculation of equipment supporting structure.

$f_c' = 30\ N/mm^2$ (Grade 30)

Reinforcing steel ASTM A615M

Grade 60, ($f_y = 420\ N/mm^2$)

Anchor bolt, ASTM A36

The model selected for this research work consists of double story RC frame supporting 37m high vertical vessels. (Vertical vessel type hoppers are a part of residual fluid catalyst cracker (RFCC), called 'catalyst hoppers. These vessels are used for storage of catalyst, supplied to plant for chemical process).

It consists of 3 bays and 2 storey frame of dimension 10m.The spacing of frame is 7.75m. Beam sizes at 7.75m level is 700*mm* x 1500*mm* in both x and z directions, and at 13.5*m* level beam size are 2000*mm* x 2000*mm* and 1800*mm* x 2000*mm* in z and x directions respectively .

The equivalent lateral forces for model structure are calculated according to seismic provisions for Lahore (zone 2A). The analysis and design are carried out using STAAD Pro 2007. Following design codes are used for analysis and design of reinforced concrete frame.

ACI 318-05 (Building code requirement for structural concrete)

ASCE 7-05 (Minimum design loads for buildings and other structures)

UBC-97: building code for seismic design

The Weight of single vertical vessel which are used in calculating seismic or wind forces are assumed here. However mostly vendor provide design loading for supporting structures.

Fabrication weight 280,000 *kg*

Erection weight 290,000 *kg*

Operating weight 1700,000 *kg*

Test (field) weight 1,700,000 *kg*

The following primary loads are used for analysis and design of equipment supporting structure as per ASCE-7-05.

1. Dead load
2. Live load
3. Equipment erection, operational and test load
4. Wind load
5. Earthquake load
6. Dynamic load

Dead and live loads are for platform only. The design of heavy equipment supporting structure is primarily governed by overturning moments due to wind and seismic loads. Structure is designed to withstand load combination in accordance with UBC-97.

Load and resistance factor design method (strength design) is used for the design of supporting structure. Analysis is done by elastic method. Structures will resist the most critical effects from the following combinations (ACI 318-05) of factored loads which are used during analysis and design.

1. $1.4D$
2. $1.2D + 1.6L + 0.5\ (L_r \text{ or } S)$
3. $1.2D + 1.6\ (L_r \text{ or } S) + (f_1L \text{ or } 0.8W)$
4. $1.2D + 1.3W + f_1L + 0.5\ (L_r \text{ or } S)$
5. $1.2D + 1.0E + (f_1L + f_2S)$
6. $0.9D+ (1.0E \text{ or } 1.3W)$

For analysis and design of equipment supporting structures MS excel spread sheet and STAAD Pro 2007 are used. Wind and seismic loads are critical for vertical vessel due to its height and weight.MS Excel spread sheet is used for wind and seismic load calculation. STAAD Pro 2007 is used to check the structural stability and design of column and beam of supporting structure.

Model description: The basic model parameters have been discussed in the preceding section. The layout of the vessels is shown in the figure-1. Self weight of the vessels is given by the manufacturer however the wind pressure and the earthquake load is measured using ASCE7-05 and UBC 1997.

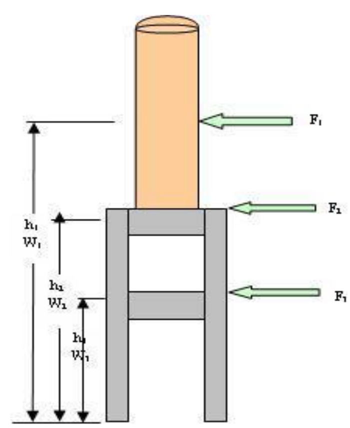

Figure-1 Plan of RCC building supporting towers (Ahmad, 2009)

The total height of the vessel above the RCC floor is 37m therefore the wind shear at the base of the vessel was found out to be 956kN and moment due wind pressure at the base was found to be 18925kN-m. The seismic shear acting at the base of each of the column in RC frame is 2290kN. The seismic shear was distributed at three levels as shown in figure-2.

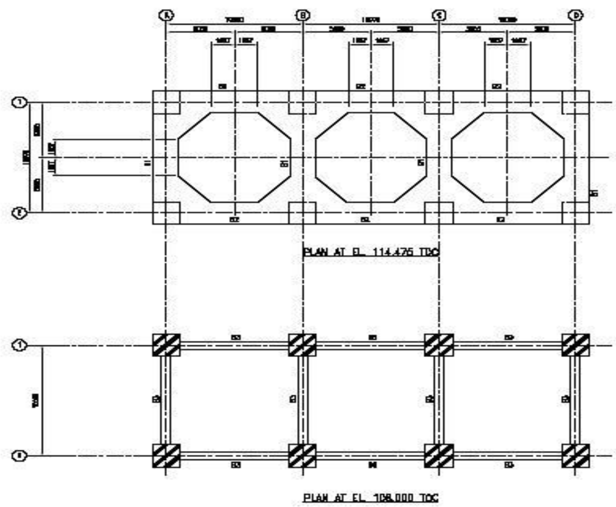

Figure-2 Application of Earthquake forces at successive levels.

Lateral forces F_1 to F_3 indicate the application of earthquake loading while h_1 to h_3 represent the height at which forces are applied. The weight of the structure considered at three different levels was represented by W_1 to W_3.

The 3D model which was developed in STAAD pro is shown in figure -3. The model was developed as per original dimensions of the vessel. The extreme care was also taken regarding defining the materials so that real time data shall be obtained from the computer model results.

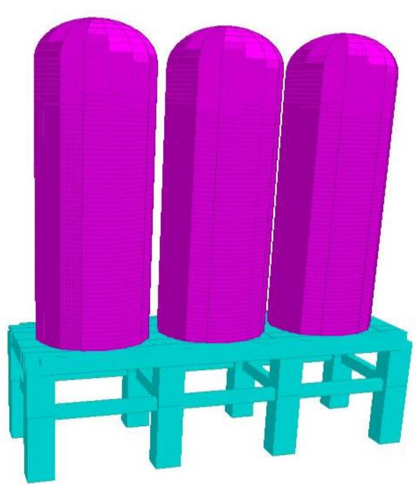

Figure-3 3D computer model for RC structures supporting vessels. (Ahmad, 2009)

RESULTS AND DISCUSSION

The salient feature observed during the analysis were as follows.

1. Wind shear at base = 956kN
2. Overturning moment due to wind = 18925kN-m
3. Earthquake shear at base = 3840kN
4. Overturning moment due to earthquake =89345kN-m
5. Horizontal sway = 11.74mm (Maximum permissible (h/200 = 68.75mm))
6. Maximum mass participation is 70.843 % in x-direction for mode shape 2 (the fundament mode in x-direction) and modal period is 0.734 seconds.
7. Maximum mass participation 70.421 % in y-direction for mode shape 1 and modal period 0.814 seconds.
8. Ratio of mass of equipment to the mass of structure is (50014/38400) = 1.3

Singh and Ang (1974) have concluded that if the ratio between mass of the equipment and the mass of the structure is less than 0.01 then the dynamic behavior of non structural component may not be considered for the primary structure. However Toro *et al*.(1989) had reduced the ratio to 0.001. Since in the present case the ratio is more than 0.01, therefore the effect of the non structural element is considered on the primary structure.

It was observed from the analysis of the computer model that conventional structure was easy to design but the critical point in the whole installation was joining of steel vessels with the concrete structure. The connection of the steel vessel with the structure was made using anchorage mechanism.

Anchorage mechanism is used to transmit the equipment load to supporting structure by means of tension and shear. Anchorage design is performed according to ACI appendix “D” and AISC references. Due to seismic forces the failure of an anchor bolt could result in loss of equilibrium or stability. Anchor bolts are designed for critical effects of factored loads, determined by elastic analysis.

The tilting effect due to heavy equipment loads are catered by stud anchor bolts. To resist shear and tension forces, vessels are anchored to the supporting structure. Ductile design of anchor bolt has been carried out, the tension and shear capacities of anchorage system are governed by the steel properties of A-bolts rather than concrete properties of supporting beams.

Anchors are used in areas of intermediate or high seismicity. The ductile failure of anchorage system has to be ensured for which A-Bolt is used. Anchor-bolt is placed and sized so that the tension and shear capacities of anchorage system are governed by the steel properties of an Anchor-Bolt rather than concrete properties of supporting beams. The typical forces and arrangement of the anchor bolt system is shown in the figure-4.

Suarez and Singh (1989) has recommended in their study that modal participation in case of equipment supporting structures both for primary and secondary structure shall be considered. They also emphasized that torsional effects is of prime importance which must also be accounted for during the response of two structures. Since in this study both the effects were considered and structure was secured for torsional effects.

Huang *et al.* (2005) studied the seismic protection of secondary elements in nuclear power plant facilities. The authors recommended that some seismic isolation for the structure will be very useful to control the time period of two structures. Since the attachments like piping are not to be disrupted during the vibration of the structures, therefore some flexibility shall be maintained for such areas in order to minimize the loss.

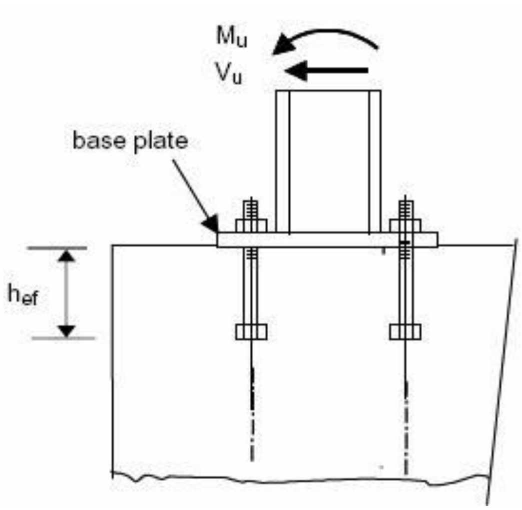

Figure-4 Typical forces and arrangement of anchor bolt system (Ahmad, 2009)

CONCLUSIONS

1. The seismic forces on equipment supporting structures are 20 to 30 % more than ordinary structure due to low lateral force resistance factor.
2. The point of contact of equipment with the concrete structure is important as it produces a lot of torque during seismic activity which results in increased sizes for beams and columns.
3. It was also found that equipment weight and its dynamic behavior is controlling the base concrete structure hence resulting in approximately 60 % more mass and stiffness as compared to ordinary structure.
4. Equipment load are transferred on supporting beams through stud anchor bolt. The strength of anchorage is related to its embedment or development length into the supporting beams. Therefore deep beams are required to provide enough embedment for developing proper anchorage.
5. The ductile failure of anchorage system is desirable for non structural components. In this regard it is recommended that concrete in which anchorage is bonded shall have sufficient strength which should not fail prior to the tension failure of anchor bolts.

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