Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 55(8) (2023) 333-336
DOI: 10.22060/ceej.2023.22107.7904

Process towers probabilistic seismic behavior evaluation using incremental dynamic analysis

F. Kolbadi[1], S. Koohestani[1], B. Sayyafzadeh[1], A. Sarvghad Moghadam[1], M. Sharifi[2]*

[1] Department of Civil Engineering, Faculty of Technical and Engineering, University of Qom, Qom, Iran
[2] Structural Engineering Research Center, International Institute of Earthquakes Engineering and Seismology (IIEES), Tehran, Iran

ABSTRACT: Process towers or vertical vessels are among the industrial structures that play a key role in the production process of petroleum products and their derivatives in refineries and oil and gas industries. Due to the vulnerability of these structures in past earthquakes, and the lack of valid regulations and methods for seismic analysis and design of these structures, a case study on a designed and constructed process tower 26.5 meters high, located in Qeshm Island Refinery, has been conducted in this research. Since considering a rigid foundation, without the interaction of soil and structure, may lead to wrong results, in this study, the tower has been modeled in Abaqus finite element software considering soil behavior. The Winkler model used for soil modeling and the seismic behavior of the tower was investigated using pushover and incremental dynamic analysis, and finally, the resulting fragility curve is presented to show the structure's vulnerability at different levels of seismic intensities. In this investigation, the probable failures, including the failure of the body and the skirt, as well as the overturning of the structure, have been investigated. According to the incremental dynamic analysis results, no buckling was observed in the body and the tower's skirt before the tower overturned. The results show that overturning was the predominant failure mode and the probability of this failure mode until PGA=0.1g is approximately equal to zero, and for PGA= 0.35g, this probability is less than 20%. But for rare seismic intensities, the overturning probability is considerable.

Review History:

Received: Jan. 17, 2023
Revised: Jun. 16, 2023
Accepted: Jun. 17, 2023
Available Online: Aug. 07, 2023

Keywords:

Process towers
Seismic assessment
fragility curve
Incremental dynamic analysis (IDA)
Soil structure interaction (SSI)

1- Introduction

During the past earthquakes, many vertical process vessels have been damaged by strong earthquakes and investigations showed this phenomenon for such structures. Seismic analysis of these structures without considering the SSI effects does not indicate the correct seismic response. This research was carried out on a constructed process tower in Qeshm Island Refinery. The modeling of this tower has been done in Abaqus finite element software considering the effects of soil and structure interaction. Seismic behavior has been investigated by performing incremental dynamic analysis and its fragility function has been generated.

As presented in most reports about the overturning of process towers, considering soil-structure interaction and removing soil tension can potentially affect structural responses [1]. Also, according to the observed damage for towers and vessels in past earthquakes, in this article, the stress in the body and skirt, the strain, and the overturning of the tower have been investigated.

2- Methodology

2- 1- Numerical modeling

The process tower studied in this research is a tower with a height of 26.5 meters and a diameter of 2.8 meters mounted steel base (skirt) with a diameter of 2.8 meters. The weight of the tower in operation condition is 204 tons.

Fig. 1. Finite element model of the tower

S4R shell element has been used to model the wall, skirt,

*Corresponding author's email: m.sharifi@qom.ac.ir

Table 1. The equation for calculating the surface stiffness of the foundation

Vertical Translation, Kz'
$GL/(1-V)[0.73+1.54(B/L)^{0.75}]$
Horizontal Translation, Ky'
$(GL/(2-V))[2+2.5(B/L)^{0.85}]$

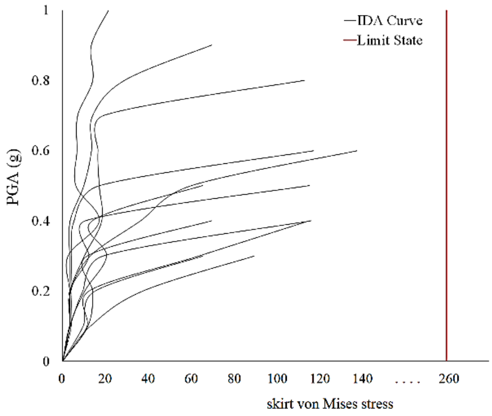

Fig. 2. IDA curve for skirt von Mises stress

top and bottom caps of the tower. The beam element is used to model the tension force of the anchor bolt. C3D8R element, which is a solid-homogeneous element, has been used to model the pedestal and foundation.

2- 2- Soil modeling

The effects of soil-structure interaction (SSI) are considered using Winkler modeling according to the ATC-40 code [2]. The stiffness of the foundation springs is obtained from the equations presented in Table 1. The foundation is placed deep in the soil, so, additional coefficients are multiplied by the corresponding stiffness.

In this article, modal analysis has been done for the structure without consideration of soil-structure interaction and for the structure with consideration of soil-structure interaction. It is observed that the period of the first mode of the tower has increased from 0.26 to 0.34 considering SSI.

2- 3- Analysis Method

12 accelerograms corresponding to the soil characteristics of the site and the distance from the fault have been selected to perform incremental dynamic analysis. PGA is considered a fine measurement parameter for representing acceleration magnitude.

For the maximum von Mises stress of the body and

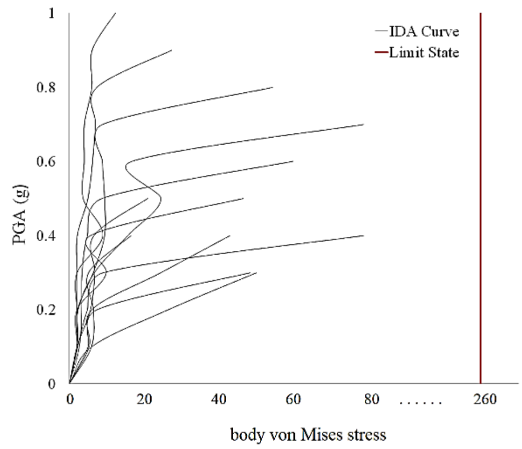

Fig. 3. IDA curve for von Mises stress of body

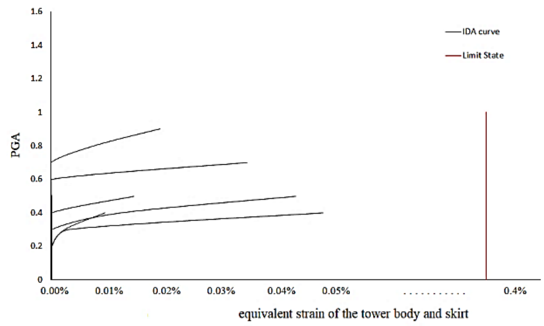

Fig. 4. IDA curve of the equivalent strain of the tower body and skirt

skirt and the equivalent plastic strain have been selected as engineering demand parameters (EDP) and according to the following limit states, the fragility curve is drawn.

Limit state:

Rupture of the tower wall: when the equivalent plastic strain, reaches a value equal to 0.4% [3].

Plastic limit: The equivalent design stress should be less than the value of yield strength mentioned in [4] and [5]. According to the characteristics of the material for the process tower shell, it is equal to 260 MPa.

3- Results and Discussion

3- 1- IDA curve

Obtained IDA curves are shown in the following figures.

3- 2- Fragility curve

According to the IDA curves, the final limit state has not been reached before the overturning of the structure, so the overturning of the structure is the dominant failure mode in this case study.

Fragility curve of the overturning has been calculated and

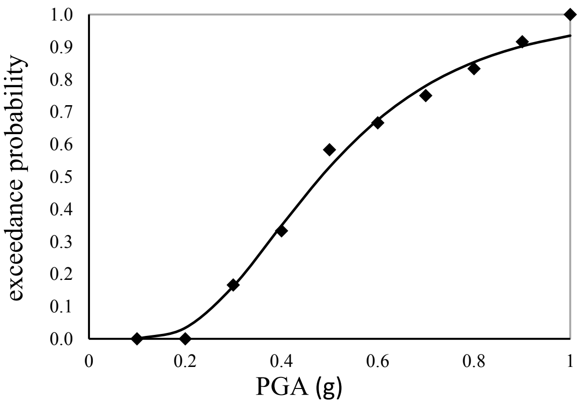

Fig. 5. IDA curve for von Mises stress of body

shown in the following figure.

4- Conclusions

According to the IDA curves, the von Mises stress and the equivalent plastic strain in the body and skirt have not reached to their limit state until the tower overturns and no yielding has been observed body shell, and this indicates that the overturning failure mode is predominate for the structure.

According to the fragility curve obtained for the structure up to g0.1 acceleration, the probability of tower overturning is zero, and for g acceleration of 0.35 this probability is less than 20%.

But in higher intensities, this value is much higher, and for rare earthquakes, the probability of overturning is numerically large and significant.

References

[1] M.a. Ronagh, Plastic Hinge Length of RC Columns Subjected to Both Far-Fault and Near-Fault Ground Motions Having Forward Directivity, The Structural Design of Tall and Special Buildings, 24 (2011) 421-439.

[2] ATC-40, Seismic evaluation and retrofit of concrete buildings volume 1 ATC-40, ATC 40, Applied Technology Council, 1 (1996) 334.

[3] K. Diamanti, I. Doukas, S.A. Karamanos, Seismic analysis and design of industrial pressure vessels, ECCOMAS Thematic Conference - COMPDYN 2011: 3rd International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering: An IACM Special Interest Conference, Programme, (2011).

[4] E. Committee for Standardisation, EN 1993-1-6: Eurocode 3 - Design of steel structures - Part 1-6: Strength and Stability of Shell Structures, in, 2011.

[5] M. Pluto, Tank Shell Design According to Eurocodes and Evaluation of Calculation Methods, Faculty of Health, Science and Technology Degree, (2018) 79.

HOW TO CITE THIS ARTICLE

F. Kolbadi, S. Koohestani, B. Sayyafzadeh, A. Sarvghad Moghadam, M. Sharifi, Process towers probabilistic seismic behavior evaluation using incremental dynamic analysis, Amirkabir J. Civil Eng., 55(8) (2023) 333-336.

DOI: 10.22060/ceej.2023.22107.7904

This page intentionally left blank