Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 54(8) (2022) 653-656
DOI: 10.22060/ceej.2022.20443.7429

# A modified lateral load pattern for linear static analysis

A. R. Habibi[1], M. Izadpanah[2*], H. Saffari[3]

[1] Department of Civil Engineering, Shahed University, Tehran, Iran
[2] Department of Civil Engineering, Kermanshah University of Technology, Kermanshah, Iran
[3] Department of Civil Engineering, University of Kurdistan, Sanandaj, Iran

**ABSTRACT:** linear static analysis is one of the most widely used methods proposed by the codes for the seismic analysis of structures. Several methods have been presented for determining the static lateral load pattern. In spite of the simplicity of these procedures, their accuracy, especially for structures in which the influences of higher modes are significant, is not desirable. In this study, a new method is developed to improve the lateral load pattern in linear static analysis. To achieve the proposed lateral load distribution, firstly, the average responses of some structures subjected to some earthquakes are acquired. Then, regarding the dynamic responses of the structures, the static lateral load pattern compatible with the average responses is developed. Eventually, to derive a straightforward and hands-on lateral load distribution, using a statistical study, some relations coupled with a graph are developed. Since the proposed method is developed based on the structural responses resulting from linear dynamic analysis (time-history analysis), it is shown that the suggested way, despite its simplicity and efficiency, presents appropriate accuracy in predicting the responses of the structures subjected to seismic excitations. The developed lateral load is applied for three frames with 5, 10 and 14 stories. The inter-story drifts of these frames are achieved under 14 earthquake excitations. After that, the proposed lateral loads of code 2800 and FEMA 356 are used on these frames and the responses are derived. The outcomes show that whereas the average error of the proposed lateral load for these frames is around 7, 5 and 7%, the average errors of code 2800 and FEMA 356 are almost 20, 10 and 25%. Comparing the inter-story drifts for the developed lateral load pattern with the dynamic results, validates its performance. The developed method is evaluated for a set of structures with different fundamental periods. Results show that the method gives higher accuracy in comparison with the static method of Iranian standard 2800 and FEMA 356. Also, the developed procedure can be considered as an appropriate technique for determining lateral load distribution in seismic codes.

**Review History:**

Received: Aug. 23, 2021
Revised: Jan. 17, 2022
Accepted: Feb. 01, 2022
Available Online: Feb. 21, 2022

**Keywords:**

Linear static analysis
Lateral load pattern
Higher modes effect
Dynamic analysis
Seismic codes

## 1- Introduction

Equivalent static analysis is one of the most practical methods for seismic analysis of buildings [1-3]. In this method, lateral load distribution throughout the height significantly affects the structural responses e.g., the damage level, internal forces and seismic behavior [4, 5]. The lateral load pattern in equivalent static analysis has been the research interest in the plethora of studies [6, 7]. Some studies focused on an optimum lateral load pattern for static analysis [8-19].

A literature review on the lateral load distributions indicates that the previous patterns have some shortcomings such as disregarding the higher mode effects and are in the same direction for the lateral forces. This study aims to develop a new lateral load distribution achieved based on dynamic analysis to boost the responses of equivalent static analysis.

## 2- Methodology

In this research, to develop the lateral load pattern, the following relations are applied:

$$\ddot{y}_i + 2\zeta\,\omega_i\,\dot{y}_i + \omega_i^2\,y_i = -\frac{L_i}{M_i}\ddot{u}_g(t) \quad (1)$$

$$L_i = \phi_i^T M r \quad (2)$$

$$M_i = \phi_i^T M \phi_i \quad (3)$$

Where ζi is damping ratio. $\omega_i$ is circular frequency . $y_i$ is the displacement of a SDOF system for mode $i^{th}$. $y_i$ can be acquired using Duhamel's integral as follow:

*Corresponding author's email: m.izadpanah@kut.ac.ir

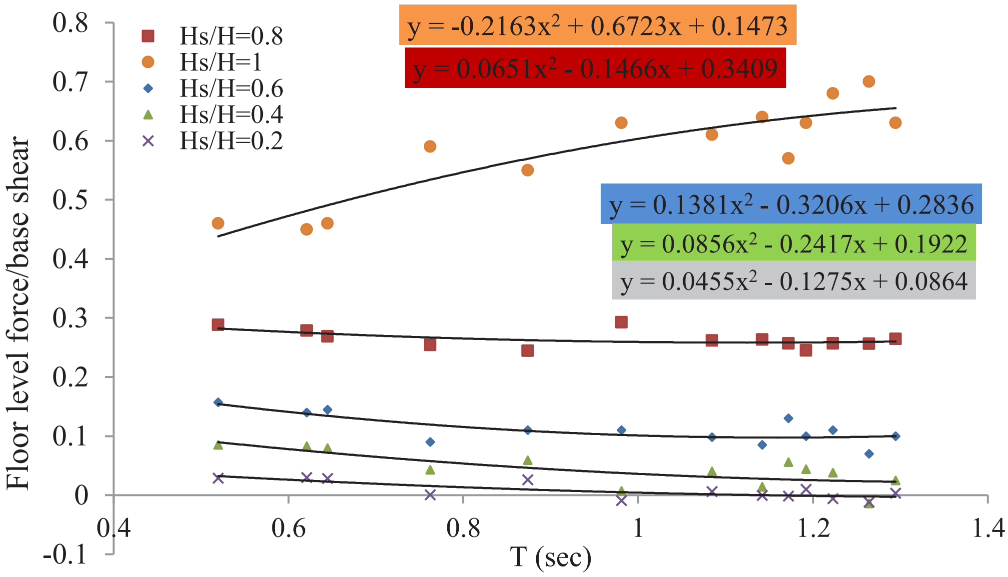


**Fig. 1. A graph for acquiring the lateral force distribution along the height of the building**

$$y_i(t) = -\frac{L_i}{M_i\,\omega_{Di}} \int_0^t \ddot{u}_g(\tau)\;^{-\zeta_i \omega_{Di}(t-\tau)} \sin \omega_{Di}(t-\tau)\, d\tau \tag{4}$$

Knowing $y_i$, the displacement of $j^{th}$ floor level is obtained as follows:

$$u_j = \sum_{i=1}^{n} \phi_{ji}\, y_i \tag{5}$$

Where $\phi_j$ is the $j^{th}$ component of the $i^{th}$ vibration mode. The drift ratio can be achieved as follows:

$$\Delta_j = u_j - u_{j-1} \tag{6}$$

Since earthquakes have different properties such as energy, frequency content and so on, for seismic analysis, the responses of several dynamic analyses should be considered.

$$\bar{\Delta}_i = \sum_{k=1}^{N_E} \Delta_{ik} \Big/ N_E \tag{7}$$

Where $N_E$ is the number of earthquakes. $\bar{\Delta}_i$ is the average of drifts for each story. Eventually, the lateral force of each floor level is achieved using Eq. .

$$F_j = k_j \bar{\Delta}_j \tag{8}$$

$k_j$ is the stiffness of the $j^{th}$ story.

To develop the lateral load, a set of steel frames (intermediate ductility) from two to fourteen stories are considered. These frames are analyzed subjected to twenty seismic ground motions from FEMA 440 for soil type C. A hands-on graph is presented for obtaining the lateral load distribution (Figure 1). In Figure 1, Hs is the height of the selected floor level and H is the height of the frame. Some interpolation relations are presented in Figure 1, to predict the floor level force/base shear (y) based on the period (x) and the ratio of Hs/H.

## 3- Results and Discussion

The proposed relations are used to analysis of seven new frames. In comparison with the dynamic responses of these frames subjected to 14 new earthquakes, the developed method presents reasonable outcomes. Comparing the inter-story drifts of these frames subjected to lateral load patterns of FEMA356, Iranian seismic code, and the developed method with the dynamic responses under earthquake excitations shows that whereas the outcomes of the developed method is close to the dynamic ones, there is a significant gap between the responses of FEMA356 and Iranian seismic code with the dynamic responses.

## 4- Conclusions

In this research, a new lateral load distribution for the equivalent static method is developed. This method which is based on dynamic responses, is capable of considering higher mode effects and the different directions for lateral forces. In this method, a graph and some relations are presented to achieve the lateral force of each floor level based on the ratio of Hs/H and the fundamental period of the frame. Evaluation of some new examples confirms the validity of the proposed procedure.

## References


[1] B. NEHRP, Recommended provisions for the development of seismic regulations for new buildings,

Washington, DC: Building Seismic Safety Council, Federal Emergency Management Agency.(1994).

[2] .E. FEMA 356, Prestandard and commentary for the seismic rehabilitation of buildings, FEMA Publication No, 356 (2000).

[3] BHRC, Iranian Code of Practice for Seismic Resistant Design of Buildings: Standard No. 2800 ,4th Edition, Building and Housing Research Center, ( 2015).

[4] H. Moghaddam, Earthquake engineering: theory and application, Tehran: Farahang, (2002)

[5] A.K. Chopra, Dynamics of Structures: Theory and Applications to Earthquake Engineering, Prentice Hall, Inc., Upper Saddle River, NJ,(1995).

[6] G.C. Hart, EARTHQUAKE FORCES FOR THE LATERAL FORCE CODE, Struct. Design Tall Build. 9(2000) 49–64.

[7] P. Wenshen, L. Zu-Hsu, L. Anson, A comparative study of seismic provisions between International Building Code 2003 and Uniform Building Code 1997, Earthquake Engineering and Engineering Vibration, 5(1) 49-60 (2006).

[8] R, K. Mohammadi, The influence of the distribution of structures' shear resistance factors on decresing the imposed damage of earthquakes, Ph. D. Dissertation, Civil Engineering Department, Sharif University of Technology, Tehran, Iran (in Persian), 2005.

[9] H. Moghaddam, I. Hajirasouliha, Toward more rational criteria for determination of design earthquake forces, International Journal of Solids and Structures, 43(9) (2006) 2631-2645.

[10] P. Ghaderi, H. Khosravi, A.R. Firoozjaee, Consideration of strength-stiffness dependency in the determination of lateral load pattern, Soil Dynamics and Earthquake Engineering, 137 (2020) 106287.

[11] M.A. Amini, M. Poursha, Adaptive force-based multimode pushover analysis for seismic evaluation of midrise buildings, Journal of Structural Engineering, 144(8) (2018) 04018093.

[12] J. Bai, H. Chen, J. Jia, B. Sun, S. Jin, New lateral load distribution pattern for seismic design of deteriorating shear buildings considering soil-structure interaction, Soil Dynamics and Earthquake Engineering, 139 (2020) 106344.

[13] A. Habibi, H. Saffari, M. Izadpanah, Optimal lateral load pattern for pushover analysis of building structures, Steel Compos. Struct, 32(1) (2019) 67-77.

[14] H. Zhang, M. Lian, M. Su, Q. Cheng, Lateral force distribution in the inelastic state for seismic design of high-strength steel framed-tube structures with shear links, The Structural Design of Tall and Special Buildings, 29(17) (2020) e1801.

[15] M. Guan, W. Liu, H. Du, J. Cui, J. Wang, Combination model for conventional pushover analysis considering higher mode vibration effects, The Structural Design of Tall and Special Buildings, 28(12) (2019) e1625.

[16] X. Cheng, T. Wang, J. Zhang, Z. Liu, W. Cheng, Finite element analysis of cyclic lateral responses for large diameter monopiles in clays under different loading patterns, Computers and Geotechnics, 134 (2021) 104104.

[17] B. Ganjavi, I. Hajirasouliha, A. Bolourchi, Optimum lateral load distribution for seismic design of nonlinear shear-buildings considering soil-structure interaction, Soil Dynamics and Earthquake Engineering, 88 (2016) 356-368.

[18] A. Fakhraddini, M.J. Fadaee, H. Saffari, A lateral load pattern based on energy evaluation for eccentrically braced frames, Steel and Composite Structures, 27(5) (2018) 623-632.

[19] I. Hajirasouliha, H. Moghaddam, New lateral force distribution for seismic design of structures, Journal of Structural Engineering, 135(8) (2009) 906-915.

**HOW TO CITE THIS ARTICLE**

*A. R. Habibi, M. Izadpanah, H. Saffari, A modified lateral load pattern for linear static analysis, Amirkabir J. Civil Eng., 54(8) (2022) 653-656.*

**DOI:** 10.22060/ceej.2022.20443.7429