Advances in Computational & Experimental Engineering & Science

OPTIMUM TRANSLATIONAL VIBRATION OF MULTI-STOREY BUILDINGS WITH VERTICAL MASS AXIS

T. Makarios[1], H. Xenidis[2]

Summary

The determination on the plan of the real or fictitious center of stiffness of a multi-storey building through which the vertical real or fictitious elastic axis passes is of great significance for a documented application of the simplified methods of seismic analysis. In the present article, a numerical investigation is performed for the correlation of the fictitious elastic axis with the optimum translational vibration in multi-storey buildings, which possess a vertical mass axis. The investigation is achieved by use of the linear dynamic time-history analysis with accelerograms of different frequency contents.

Introduction

On one hand, in the general case of multi-storey systems, it is not possible to define a static eccentricity e independent from the external loading [1],[2],[3]. On the other hand in every multi-storey asymmetrical system, which possesses the required -by the Codes- regularity over its height, the axis of optimum torsion is always defined, alternatively called fictitious elastic axis, that is a vertical axis having the property that if the lateral static seismic forces are imposed on it, then the torsion of the whole system is minimized [4]. In the last case, the rotations of the storeys become negligible and consequently, within the usual approximations accepted by the simplified methods of seismic analysis, it can be assumed that the system is subjected to translation without torsion. For this reason, the point P_O of the plan through which the vertical axis of optimum torsion passes, can play the role of center of stiffness of the structure, in a documented application of the simplified modal analysis of seismic design. The present article refers to multi-storey assymetrical buildings, which have the required -by the Codes- regularity over its height, in which the mass centers of all the floors lie on the same vertical axis that then will be called “vertical mass axis”. In these buildings, the possibility of determining the optimum translational vibration is examined, so that the additional requirements for ductility of perimetric vertical structural element will be minimized. That is, the ductility requirements of all the vertical structural elements will be limited to the requirements for a clear translational

1 Researcher of Institute of Engineering Seismology and Earthquake Engineering, Greece, e-mail: makarios@itsak.gr,

2 Assistant Professor, Department of Civil Engineering, Aristotle University of Thessaloniki, Greece e-mail: xharis@civil.auth.gr

Advances in Computational & Experimental Engineering & Science
Copyright 2004 Tech Science Press

vibration of the buildings as exactly happens in the single-storey systems [5]. For the needs of the present work, an extended parametric analysis in multi-storey buildings was performed by use linear dynamic time-history analyses with ten accelerograms of different frequency content. From the whole of the examined cases is shown here a representative ten-storey frame-wall monosymmetric system. For the numerical verification of the optimum translational vibration of the building, the criterion of minimization of the quantity $\bar{\theta}^2$ was used, which is obtained from the equation (1) where θ_i the maximum rotation (as mean value of maximum rotations from ten different accelerograms –see section 1631.6.1 of UBC-1997) of the i-th floor (i=1,2,…,N) around a vertical axis and N the number of floors:

$$\bar{\theta}^2 = \left(\theta_1^2 + \theta_2^2 + \ldots + \theta_N^2\right) / N = \text{minimum} \qquad (1)$$

From the analyses it resulted that the position of the vertical mass axis corresponding to the optimum translational vibration of the multi-storey building, is that coinciding with the vertical axis of optimum torsion, which passes through the point P_o .

Analysis

For the ten-storey monosymmetric system of figure 1 the following data are given (S.I. unit):

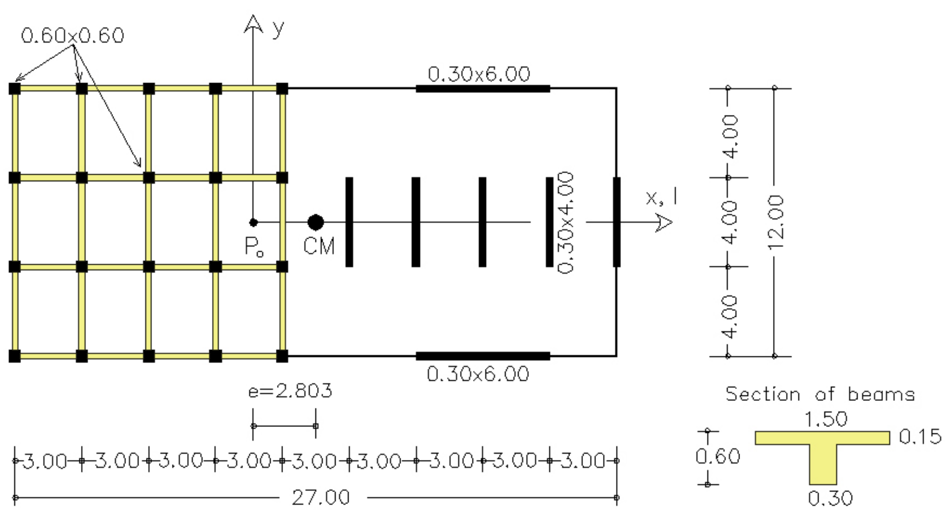

Figure 1:Plan of a ten-storey systsem.

Building's height H=10 x 3.50m=35.0m, columns (0.60m)x(0.60m) constant in all the storeys, structural walls with a constant section in all storeys with dimensions (0.30m)x(4.00m) along y direction and (0.30m)x(6.00m) along x direction, inertia moment of beams section $I_b = 0.0103\ m^4$, elasticity (Young) modulus E=29 GPa and Poison ratio v=0.15. The frames and the structural walls co-work to each other because of the diaphragm operation at the floor levels. A storey mass M=400.t (SI) was considered concentrated at the geometrical center CM of every diaphragm, whereas the corresponding mass inertia moment J_m around the vertical axis passing through the center of mass CM equals to $J_m = 29100\ t \cdot m^2$. From the analysis procedure results that the vertical axis of optimum torsion of the building passes through the pole of twist $P_o(X_P, Y_P)$ of the level $z_o = 0.80H$ as shown in figure 1 [4] .

Linear dynamic time-history analysis.

For the needs of the present article, a linear dynamic time-history analysis was performed using the accelerograms of different frequency content, which are shown in table 1. All ten accelerograms were oriented along the y horizontal directions, whereas for comparison reasons, a second seismic component was not simultaneously used along the other principal direction of the building. The resulting displacements of the floors from every time-history analysis were normalized with respect to the maximum displacement of the optimum torsion axis P_o at the top of the building for comparison reasons. The values of displacements of fig.2 constitute the mean of the normalized maximum appearing (non simultaneous) values from the ten linear dynamic time-history analyses (section 1631.6.1 of UBC-1997). Many cases were examined for different position of the vertical mass axis, from which, in this article, the results of displacements are presented for the following two cases (fig.2): (a) In the first case, it was considered that the vertical mass axis coincides with the optimum torsion axis, that is it passes through the point P_o , whereas the maximum non-simultaneous displacements are shown in fig.2 by shadowing (values within the parentheses). From the picture of displacements, we observe that, in this case, the building is mainly subjected to translation, without important torsional vibrations. In other words, in the case that the vertical mass axis coincides with the optimum torsion axis, we approach the optimum translational vibrations of the whole building and the ductility requirements of all vertical structural elements are limited to the requirements for a clear translational vibration of the building. Indeed, by using the criterion of equation (1), it results that the index

Advances in Computational & Experimental Engineering & Science

$\overline{\theta}^2$ takes the minimum value min $\overline{\theta}^2 = 0.000339 = \overline{\theta}^2_{Po}$ (by use of the mean normalized values of floors rotations). Finally, it is noted that the maximum appearing floor displacements from the ten linear dynamic time-history analyses are, compared to the mean values of fig.2, on one hand for the left side increased by 26% in the 1^{st} floor and gradually reducing to 3% at the top of the building, whereas on the other hand, for the right side, they are increased about 7% , which is independent from the floor.

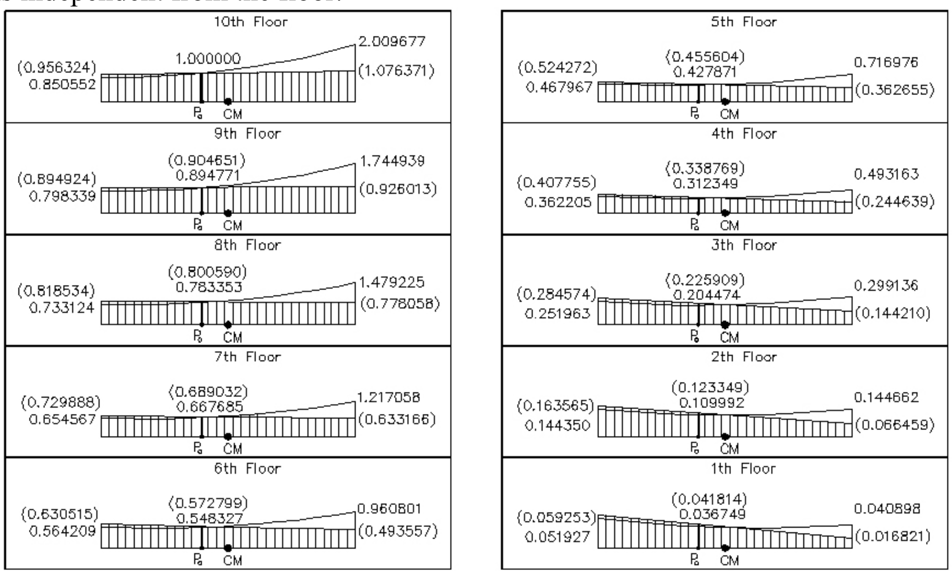

Figure 2:Diagrams (in m) of the maximum displacements of the floors (mean normalized values) .

(b) In the second case, it was considered that the vertical mass axis passes through the center of mass CM of the diaphragm (values without parenthesis in fig.2). We observed that normally the right side of the floors appears a larger displacement than the left side and this shows that the flexible side of the building is the right side of all the storeys, in spite of the fact that in this side the structural walls have been located. This is due to the significant storey rotations that appear in the linear dynamic time-history analyses. Indeed, by using the criterion of equation (1) it results that the index $\overline{\theta}^2$ takes now the value $\overline{\theta}^2_{CM} = 0.024392$ that is about 72 times larger than the minimum one min $\overline{\theta}^2$ =0.000339 . Here it must be emphasized that as the vertical mass axis

Advances in Computational & Experimental Engineering & Science

removes from the optimum torsion axis, the index $\bar{\theta}^2$ of equation (1) gets always-larger values. Finally, it is noted that the maximum appearing storey displacements from the ten dynamic time-history analyses are, compared to the mean values of fig.2, on one hand, for the left side increased by 31% at the 1st floor and gradually grow up to 52% at the top of the building, whereas on the other hand for the right side, they are increased by 22%, which is independent from the storey.

Table 1: Accelerograms.

	Earthquake, Location, Date, Magnitude.	Recording Station	Peak Ground Acceleration.	
1	Lefkada, Greece, 14.08.2003, M=6.4	Hospital of Lefkada	PGA=0.340g	N65E
2	Lefkada, Greece, 14.08.2003, M=6.4	Hospital of Lefkada	PGA=0.416g	N335E
3	Kocaeli, Turkish, 17.08.1999, M=7.4	Duzce	PGA=0.312g	h180
4	Kocaeli, Turkish, 17.08.1999, M=7.4	Duzce	PGA=0.358g	h270
5	Kobe, Japan, 16.01.1995, M=6.9	OKJMA	PGA=0.821g	h0
6	Kobe, Japan, 16.01.1995, M=6.9	OKJMA	PGA=0.599g	h90
7	Northridge, USA, 17.01.1994, M=6.7	24278 Castaic-Old Ridge Route	PGA=0.568g	h90
8	Northridge, USA, 17.01.1994, M=6.7	24278 Castaic-Old Ridge Route	PGA=0.514g	h360
9	Loma Prieta, USA, 18.10.1989, M=6.9	57007 Corralitos	PGA=0.644g	h0
10	Loma Prieta, USA, 18.10.1989, M=6.9	57007 Corralitos	PGA=0.479g	h90

Conclusions

In this article, it was parametrically investigated the determination of the optimum translational vibration in asymmetrical buildings, which posses a vertical mass axis. Applying linear dynamic time-history analyses with accelerograms of different frequency content made the investigation. From the total of the various positions of the vertical mass axis, which were systematically examined in many multi-storey buildings, a representative ten-storey asymmetrical frame-wall building was shown, whose results refer to the following two cases: (a) The vertical mass axis coinciding with the optimum torsion axis, and (b) the vertical mass axis lying on the geometric center CM of

Advances in Computational & Experimental Engineering & Science

the diaphragm. The results of the analyses lead to the conclusion that the index $\bar{\theta}^2$, determined by equation (1), is minimized in the case that the vertical mass axis coincides with the optimum torsion axis. Consequently, the state of optimum translational vibration is realized in the case that the vertical mass axis of the multi-storey building coincides with the optimum tosrsion axis that is it also passes through the point P_o of the plan too.

References

1. Riddell, R.- Vasquez, J. (1984).:“Existence of Centers of Resistance and Torsional Uncoupling of Earthquake Response of Buildings", **proc. 8th World Conf. on Earthquake Eng., 4**, p.p. 187-194.

2. Anastassiadis, K. (1985): "Caracteristiques Elastiques Spatiales des Batiments a' Etages", **Annales de I' I.T.B.T.P., No 435**.

3. Hejal, R.-Chopra, A.K.(1987):´´Earthquake response of torsionally-coupled buildings´´, **report No UCB/e.e.r.c.-87/20,** Berkeley.

4. Makarios, T. - Anastassiadis, K.(1998):´´Real and Fictitious Elastic Axis of Multi-Storey Buildings: Theory.´´, **The Structural Design of Tall Buildings, Vol. 7, Number 1, p.p. 33-45**.

5. Anastassiadis, K. - Athanatopoulou, A. - Makarios, T. (1998): ´´Equivalent Static Eccentricities In the Simplified Methods of Seismic Analysis of Buildings´´, **Earthquake Spectra the Profes. Jour. of the Earth. Engin. Research Inst., vol. 14, Number 1**.