Mansoura Engineering Journal

Volume 26 | Issue 3 Article 5

1-31-2021

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Recommended Citation
Seleemah, Ayman and Abou-Rayan, A. (2021) "Three Dimensional Seismic Analysis of High Rise Symmetric and Unsymmetric Setback Structures.," *Mansoura Engineering Journal*: Vol. 26 : Iss. 3 , Article 5.
Available at: https://doi.org/10.21608/bfemu.2021.145190

Mansoura Engineering Journal, (MEJ), Vol. 26, No. 3, September 2001.

THREE DIMENSIONAL SEISMIC ANALYSIS OF HIGH RISE SYMMETRIC AND UNSYMMETRIC SETBACK STRUCTURES

التحليل الزلزالى ثلاثى الأبعاد للمنشآت العالية ذات الردود المتماثل وغير المتماثل

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خلاصة :

قد يتطلب الحال نتيجة لوجود قيود معينة فى شروط البناء أو لأغراض معمارية إنشاء مبانى ذات ردود. تم فى هذا البحث دراسة سلوك المنشات العالية ذات الردود المتماثل وغير المتماثل تحت تأثير الزلازل وذلك بأستخدام إسلوب التتبع الزمنى الديناميكى. وقد تم الأخذ فى الأعتبار عديد من إرتفاعات الأدوار التى قد يحدث بها الردود وكذلك كمية الردود ذاتها. وقد تم إختبار تأثير هذه المتغيرات على قيم السلوك الناتجة.

أهم قيم السلوك التى تمت دراستها هى زمن التردد الطبيعى الإنتقالى والإلتوائى. وكذلك إزاحات أدوار الردود وإزاحات الدور العلوى وقوى القص وعزوم اللى المتولدة عند منسوب الأساسات. وكذلك كمية الطاقة المنقولة من الزلزال إلى المنشآ. تشير النتائج إلى إمكانية عمل علاقات مبسطة (بغرض إستخدامها فى الكود) وذلك لربط سلوك المنشآت ذات الردود بنظيرتها المستمرة بكامل الإرتفاع (أى بدون ردود).

ABSTRACT

For architectural reasons or restrictions imposed by local laws, many multistory buildings are designed with setbacks. In this paper, the behavior of high rise symmetric and unsymmetric setback structures under the effect of ground motion excitation is investigated using time history dynamic analysis. Several setback sizes and levels have been considered. Effects of setback parameters on key response values of the structures were examined. These response values include fundamental translational periods of vibration, torsional periods of vibration, setback level displacement, top story displacement, base shear, base torsional moment and maximum input earthquake energy. Results indicate the feasibility of obtaining satisfactory code formulas to relate key response parameters of a setback structure to the corresponding uniform one.

Accepted September 24, 2001

INTRODUCTION

For architectural reasons or restrictions imposed by local laws, many multistory buildings are designed with setbacks. A setback is defined to be a sudden change in plan dimensions or a sudden change of stiffness along the building height. In its simplest form, a building with setback can be considered as two parts, a tower above the setback level and a base below the setback level. According to the relative location of the tower to the base, setback structures can be classified to symmetric and unsymmetric (eccentric) setbacks [see Fig. (1)].

Current seismic building codes ignore the effect of setback if the plan area of tower exceeds 75% of base area (UBC 1997 and the Egyptian Code of Practice 1995), This ratio is called the setback size. However, for less setback sizes, both codes require dynamic analysis procedures. For unsymmetric setback structures, most code provisions require three dimensional dynamic analysis.

SEAOC (1967) and NBC (1977) may be the only code provisions that contain detailed instructions involving approximate analysis procedure for symmetric setback structures. However, the method is not only lengthy but also yields very conservative results. It should be mentioned that SEAOC (1967) was originally developed for the state of California to meet certain characteristics of ground motions in that area.

Some investigators proposed simple analysis methods of structures with setbacks. They based their proposals on either analytical investigations (Cheung 1987 and Zaghloul 1992), or experimental results (Shahrooz 1987 and 1990). Wood (1986 and 1992) made experiments on nine-story setback and stepped structures. He concluded that, setback frames were not observed to be more susceptible to damage or higher mode effects than frames with uniform profile. Such results are encouraging that approximate methods may be assessed for setback structures. Structures having vertical irregularity have also received attention (Moehle 1986, Guler 1996 and Yong 1999). Such structures are comparable to setback structures in the sudden change of stiffness, mass, or strength.

The main objective of the present study is to help in the understanding of the relations between key response parameters of a setback structure and the corresponding uniform one. These response values include fundamental translational periods of vibration, torsional periods of vibration, setback level displacement, top story displacement, base shear and base torsional moment in addition to maximum input earthquake energy. Another objective is to gain some insight into the difference in behavior between symmetric and unsymmetric setback structures.

DEFINITION OF SETBACK PARAMETERS

As shown in Fig. (1), the setback level parameter (Ls) is defined as the ratio of base height (Hs) to the total height (H). That is,

Ls = Hs / H.. (1)

The setback size (Cs) is defined as the ratio of tower area (As) to base area (A). That is,

Cs = As / A..(2)

STRUCTURAL MODEL

The current study was performed on thirty story buildings composed of reinforced concrete columns, shear walls and flat slabs. Fig. (1) shows a general layout of the structural system. Plan dimensions of the uniform structure are 45.0 m by 25.0 m. Total height is 90.0 m. The structure consists of 9 bays in the X-direction and 5 bays in the Y-direction. The average floor weight was assumed to be 1.0 t/m^2, which is the typical loading for residential and office buildings. Moreover, it was designed according to current Egyptian Code without making any special consideration for setbacks.

A total of 40 setback structures in addition to the uniform structure were analyzed under the effect of three simultaneous components of ground motion. To make the difference of the structural behavior in the X and the

Y-directions independent of the input ground motion, same input motion (50% of El-Centro N90W component) was applied in these two directions. Moreover, 50% of the vertical component of El-Centro earthquake was applied in the vertical direction. The reason for de-amplification of the input ground motion is to achieve a moderate intensity earthquake that may lie within the requirements of current building codes' provisions.

In the set of structures with symmetric setbacks, a wide range of setback sizes could be covered. These are Cs=0.11, 0.33, **0.56**, and **0.78**. On the other hand, however, such wide range could not be covered in the set of unsymmetric setback structures. Due to limitations associated with the geometric configuration of the system, values of Cs less than 0.56 could not be investigated. Instead, values of Cs=**0.56**, 0.67, **0.78**, and 0.89 were investigated.

It should be noted that, there are two values of setback sizes that are common between both the symmetric and unsymmetric setback systems. These are **Cs=0.56** and **Cs=0.78**. To facilitate the comparison between the two systems, in all the figures presented in this paper, straight lines represent cases of setbacks having these Cs values; where dotted lines represent other Cs values.

ASSUMPTIONS

The analysis was made based on the following assumptions.

1- Base supports are considered totally fixed.

2- The structure remains in the linear-elastic range. This is expected to be valid for response under design seismic loads.

3- Floor slabs are considered very stiff in their plane. So, each floor translates and/or rotates in a rigid body motion.

RESULTS AND DISCUSSION

Fig. (2) demonstrates the variation of the fundamental translational periods of vibration in the X and the Y-directions together with the torsional period of vibration for the symmetric and unsymmetric setback systems with different setback parameters (Ls and Cs). For the fundamental period in X and Y-directions, the general trend is identical and in agreement with that observed by Zaghloul (1992). The fundamental period is directly proportional to the setback size Cs. Increasing Ls up to a certain limit causes the fundamental period to decrease after which the fundamental period increases. This limit lies around Ls=0.5. The fundamental period in the X-direction is indeed identical for both the symmetric and unsymmetric setback systems. This may suggest that both systems can be considered as symmetric as far as the X-direction is concerned.

For the same setback size Cs, the fundamental period in the Y-direction for the unsymmetric setbacks is longer than those of the symmetric setback structures. The cause of this trend is that, in unsymmetric setbacks, the motion in the Y-direction is not purely translational. Rather, it is coupled with some torsion.

The torsional period of vibration is nearly identical in both the symmetric and unsymmetric setback systems. It is directly proportional to the setback size Cs and the setback level Ls. More detailed results on the fundamental translational periods of vibration and the torsional periods of vibration are reported in Table (1).

The ratio of setback level displacement to the top story displacement (Ds/Dt) is illustrated in Fig. (3) for both the symmetric and unsymmetric setback systems. As can be seen from the figure, except for the case with Cs = 0.11 (i.e. very small Cs), the ratio (Ds/Dt) has a negligible dependency on the setback size Cs specially for the structures with unsymmetric setbacks. Also (Ds/Dt) is linearly dependent on Ls. The following proposed expression might be used to represent such relation.

$$Ds/Dt = 1.2\,Ls - 0.15 \quad \text{.........................} (3)$$

Equation (3) is plotted on the graphs of Fig. (3). Obviously it gives a reasonable estimate of the displacement at the setback level as a ratio of the top story displacement. Such relation may be useful in establishing a code formula to obtain the setback level displacement provided that the top story displacement is known or vice versa.

Fig. (4) shows the ratio of setback level displacement (Ds) to the corresponding level displacement of the uniform structure (Dus). Clearly the setback level displacement (Ds) is always less than the corresponding level displacement of the uniform structure (Dus). The values of (Ds) approaches those of (Dus) at large size and high level of setback. For the same setback level Ls, the ratio (Ds/Dus) increases as Cs increases. Moreover, for each Cs value, the ratio (Ds/Dus) increases approximately linearly as Ls increases. The only exception of the linearity of the trend lies in the case with Cs = 0.11 (i.e. very small Cs). This linear trend is valid for the symmetric setback in both X and Y-directions and in the unsymmetric setbacks in the X-direction (the direction in which the system may be considered as symmetric). In the Y-direction however, not only some deviation from the linearity but also smaller Ds values are observed. The curves shown in Fig. (4) suggest that there may be a good correlation between the setback level displacement and the corresponding level displacement of the uniform structure.

The results shown in Fig. (5) represent the top story displacement of the symmetric and unsymmetric setback structures normalized to that of the uniform structure. The results are almost identical for the X and Y-directions of the symmetric setback structures. Moreover, the X-direction of the unsymmetric setback structures has the same trend of both directions of the symmetric setback structures. As mentioned earlier, the system may be considered as symmetric in this direction. Except for very small Cs value (Cs=0.11), the results indicate that the top story displacements of setback structures are about 96% to 108% of that of the uniform structure. No specific dependency on Cs or Ls can be observed.

In the Y-direction of the unsymmetric setback structures, the top story displacements are always less than those of the uniform structure. This observation is compatible with that reported by Hejal (1989). The cause of such behavior is related to the existence of lateral-torsional coupling associated with the displacement response. As shown in the figure, the top story displacements are directly proportional to setback size Cs and tend to approach those of the uniform structure at large setback sizes (Cs = 0.89).

The effect of setback parameters on the ratio of base shear of the setback structures (V) to that of the uniform structure (Vu) is shown in Fig. (6). Clearly the behaviors in the X or the Y-direction of the symmetric setback structures together with the behavior in the X-direction of the unsymmetric setback structures are identical. This confirms the conclusion that, the unsymmetric setback structures can be considered as symmetric as far as the direction parallel to the axis of symmetry of the structure is concerned.

The Y-direction of the unsymmetric setback structures gives smaller base shear response values. This observation is in agreement with that reported by Hejal (1989). Moreover, this base shear is directly proportional to both the setback size Cs and level Ls [see right-bottom graph of Fig. (6)].

In all cases except for the case with very small setback size (Cs=0.11), the base shears in the setback structures are less than those of the uniform structure. This is due to the fact that, in a setback structure, the total weight is always less than that of the uniform structure. For the case with Cs = 0.11, very apparent fluctuation of the results is observed. This is due to contribution of higher modes to the response. Moreover, surprisingly, the base shear in the case with high setback level exceeds that of the uniform structure. Thus, caution should be taken when dealing with such small setback sizes. In such cases, a complete dynamic analysis of the structure may be recommended.

The torsional moment acting at the base of the unsymmetric setback structures is shown in Fig. (7). Due to the eccentricity of loading in such systems, a considerable amount of torsion occurs at the base. This torsion is inversely proportional to the setback size Cs. Increasing Ls causes the torsional moment to increase up to a certain limit (Ls ~ 0.5) in which increasing Ls causes the torsional moment to decrease. It should be noted that, in this study, the location of the shear walls (core) was unchanged. In practical cases however, the location of the core may be changed to minimize the eccentricity and hence the base torsional moment as much as possible.

Fig. (8) shows the maximum input energy in each case normalized to that of the uniform structure. The absolute input energy is defined as the work done by the base shear on the ground displacement. As shown in Fig. (8), for cases with small setback sizes ($Cs = 0.11$ or 0.33) and high setback level, the input energy reached 110% to 125% of that of the uniform structure. However, for medium and large setback sizes ($Cs > 0.5$), the input energy in both symmetric and unsymmetric setback structures is less or at the most very slightly larger than that of the uniform structure (65% to 107%).

CONCLUSIONS

In an effort to understand the earthquake response of setback structures, a three dimensional analysis of high rise symmetric and unsymmetric setback structures including several setback sizes and levels was performed. Such analysis covers a type of structures that can be classified as long period setback structures. Based on the results presented in the study, the following conclusions can be made:

1- Unsymmetric setback structures can be treated as symmetric as far as the direction parallel to the axis of symmetry is concerned.

2- For symmetric setback structures, simple relationships can be obtained to reasonably estimate the setback level displacement, top story displacement and base shear. However, many earthquake input motions along with statistical analysis should be utilized to approach confident code formulas.

3- Equation (3), proposed in this study, gives a simple yet reasonable approximation of the ratio of setback level displacement to top story displacement.

4- For structures with very small setback sizes (say $Cs < 0.3$), no specific trend is observed and thus no correlation can be made to refer the response parameters of the setback structure to those of the uniform one. In this case accurate analysis including time history analysis may be recommended.

5- Response of unsymmetric setback structures is associated with an amount of torsional coupling that depends on Ls and Cs. This torsion results in increased fundamental translational period of vibration in the direction normal to the axis of symmetry of the structure. Moreover, it causes reduction in setback level displacement and top story displacement, reduction of base shear plus increased base torsional moment. This torsional moment may be reduced by proper and careful selection of the position of the main lateral force resisting system.

REFERENCES

[1] Cheung, V.T. and Tso, W.K. (1987) "Lateral Load Analysis for Buildings with Setback." Journal of Structural Engineering, ASCE, Vol. 113, No. 2.

[2] Egyptian Code of Practice (1995)

[3] Guler, K. (1996) "Dynamic Behavior of a Building Having Vertically Irregular Structural System." European Workshop on Seismic Behavior of Asymmetric and Setback Structures, Isle of Capri, Italy.

[4] Hejal, R. and Chopra, A.K. (1989) "Lateral Torsional Coupling in Earthquake Response of Frame Buildings." Journal of Structural Engineering, ASCE, Vol. 115, No. 4.

[5] Moehle, J.P. and Alarcon, L.F. (1986) "Seismic Analysis Methods for Irrigular Buildings." Journal of Structural Engineering, ASCE, Vol. 112, No. 6.

[6] NBC (1977) "National Building Code of Canada" National Research Council of Canada, Ottawa, Canada.

[7] SEAOC (1967) "Recommended Lateral Force Requirements and Commentary" Stractural Engineering Association Of California, USA.

[8] Shahrooz, B.M., Moehle, J.P., and Pantazopoulou, S.J. (1987) "Shaking Table Tests of a Six-Story R/C Frame with Setback." Proc. 5th Canadian Conference on Earthquake Engineering, Ottawa, Canada.

[9] Shahrooz, B.M.and Moehle, J.P. (1990) "Seismic Response and Design of Setback Buildings." Journal of Structural Engineering, ASCE, Vol. 116, No. 5.

[10] UBC (1997) "Uniform Building Code." International Conference of Building Officials.

[11] Wood, S.L. (1986) "Experiments to Study the Earthquake Response of Reinforced Concrete Frames with Setbacks." Ph.D. Thesis, University of Illinois, Urbana, USA.

[12] Wood, S.L. (1992) "Seismic Response of R/C Frames with Irregular Profiles." Journal of Structural Engineering, ASCE, Vol. 118, No. 2.

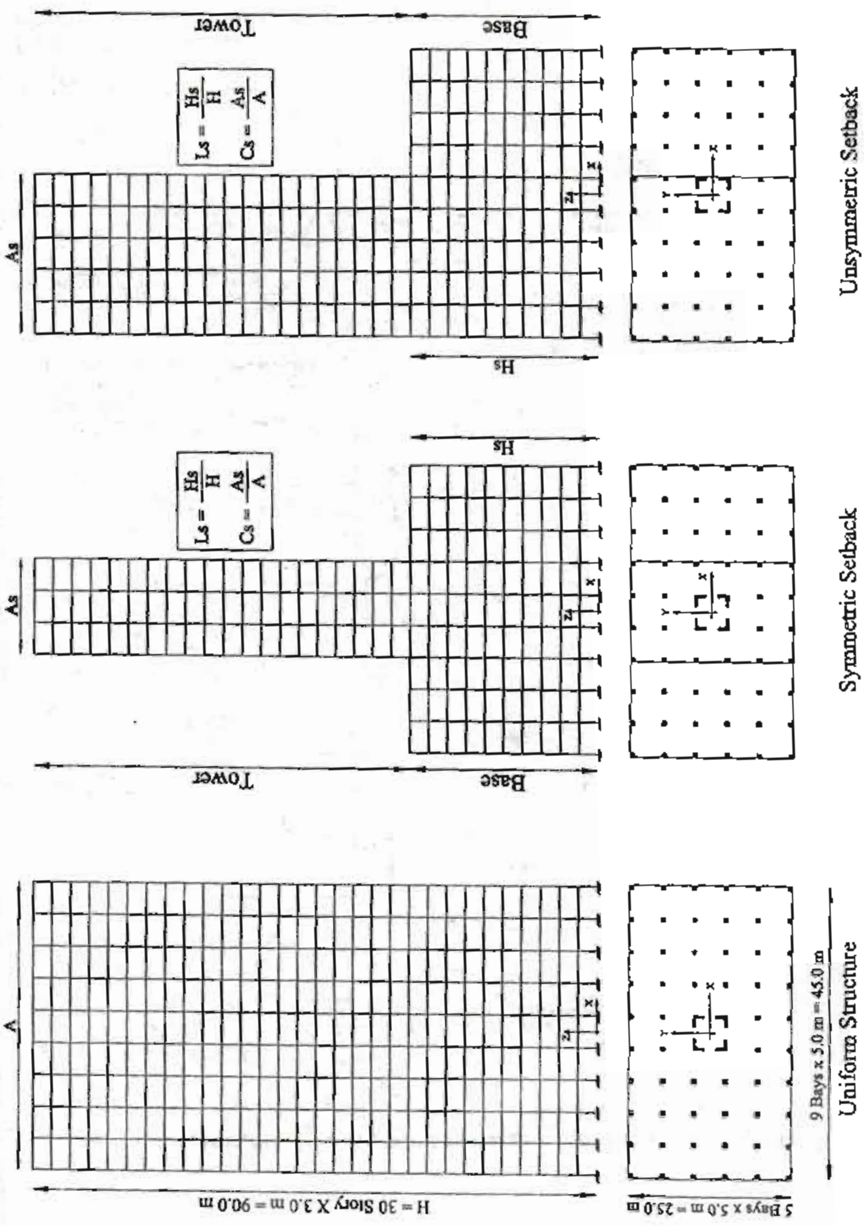
[13] Yong, L., Tassious, T.P., Zhang, G.F., and Vintzileou, E. (1999) "Seismic Response of Reinforced Concrete Frames with Strength and Stiffness Irregularities." ACI Structural Journal, Vol. 96, No. 2.

[14] Zaghloul, S.A. (1992) "Earthquake Analysis of Setback Structures." M.Sc. Thesis, Cairo University.

Table (1) Results of the Fundamental Translational Periods and Torsional Periods of Vibration

Structural Shape			Fundamental Period in X-Direction Tx (sec)		Fundamental Period in Y-Direction Ty (sec)		Torsional Period* (sec)
			Tx	Mode Shape	Ty	Mode Shape	
Uniform Structure			3.72	First Mode Pure Translation	3.79	First Mode Pure Translation	3.06
Symmetric Setback Structures	Cs=0.11	Ls=0.17	3.10	First Mode - Pure Translational Vibration	2.91	First Mode - Pure Translational Vibration	0.83
		Ls=0.33	2.69		2.58		1.04
		Ls=0.50	2.40		2.38		1.52
		Ls=0.67	2.59		2.62		2.02
		Ls=0.83	3.10		3.15		2.54
	Cs=0.33	Ls=0.17	3.38		3.31		1.39
		Ls=0.33	3.11		3.08		1.39
		Ls=0.50	2.89		2.91		1.69
		Ls=0.67	2.95		2.99		2.12
		Ls=0.83	3.26		3.32		2.59
	Cs=0.56	Ls=0.17	3.52		3.53		1.95
		Ls=0.33	3.35		3.37		1.89
		Ls=0.50	3.21		3.26		2.02
		Ls=0.67	3.23		3.29		2.31
		Ls=0.83	3.42		3.49		2.67
	Cs=0.78	Ls=0.17	3.62		3.67		2.52
		Ls=0.33	3.54		3.60		2.46
		Ls=0.50	3.47		3.55		2.49
		Ls=0.67	3.48		3.55		2.62
		Ls=0.83	3.57		3.64		2.82
Unsymmetric Setback Structures	Cs=0.56	Ls=0.17	3.51	First Mode - Pure Translational Vibration	3.67	First Mode - Coupled with Torsional Vibration	1.91
		Ls=0.33	3.35		3.59		1.84
		Ls=0.50	3.22		3.52		1.96
		Ls=0.67	3.25		3.49		2.31
		Ls=0.83	3.43		3.59		2.72
	Cs=0.67	Ls=0.17	3.58		3.70		2.20
		Ls=0.33	3.46		3.64		2.12
		Ls=0.50	3.36		3.59		2.18
		Ls=0.67	3.37		3.57		2.43
		Ls=0.83	3.51		3.62		2.76
	Cs=0.78	Ls=0.17	3.63		3.72		2.49
		Ls=0.33	3.55		3.68		2.42
		Ls=0.50	3.49		3.64		2.44
		Ls=0.67	3.49		3.63		2.60
		Ls=0.83	3.58		3.67		2.83
	Cs=0.89	Ls=0.17	3.68		3.75		2.78
		Ls=0.33	3.63		3.73		2.74
		Ls=0.50	3.60		3.70		2.75
		Ls=0.67	3.60		3.70		2.81
		Ls=0.83	3.65		3.72		2.93

* Pure Torsional Motion

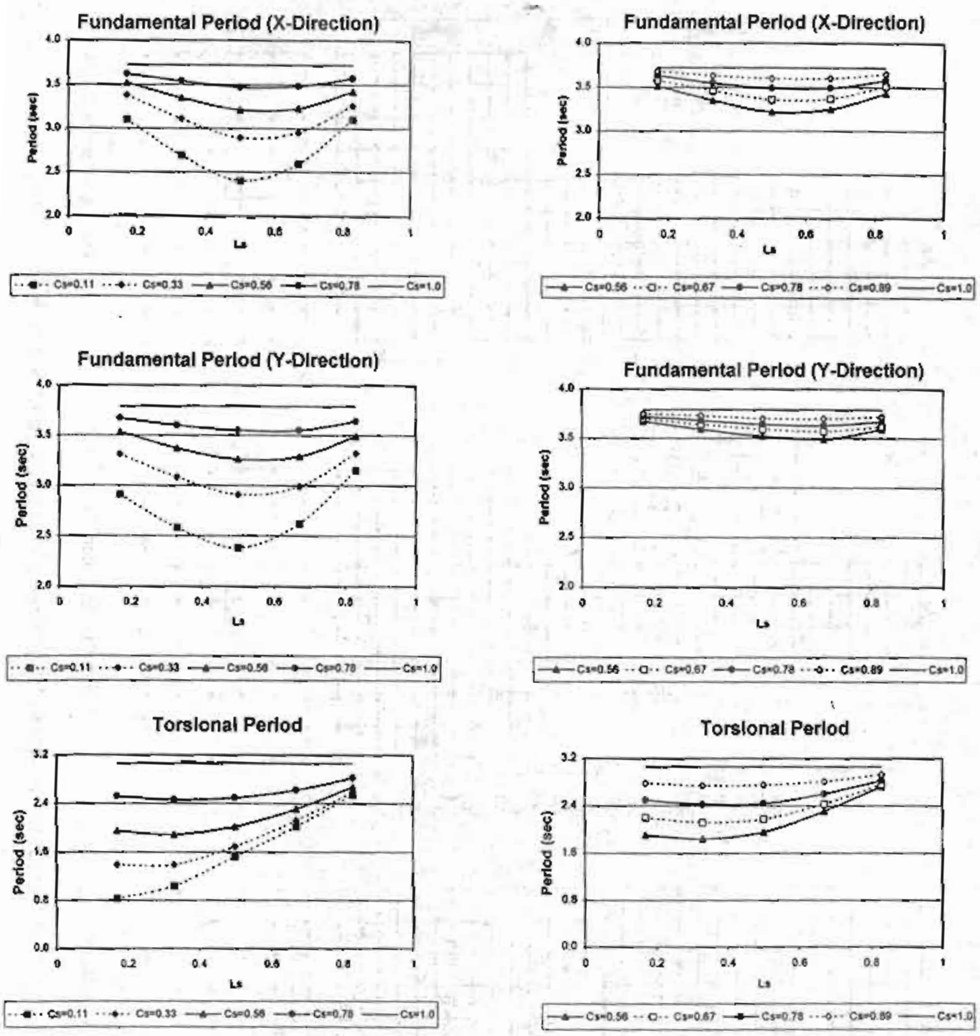


Uniform Structure

Symmetric Setback

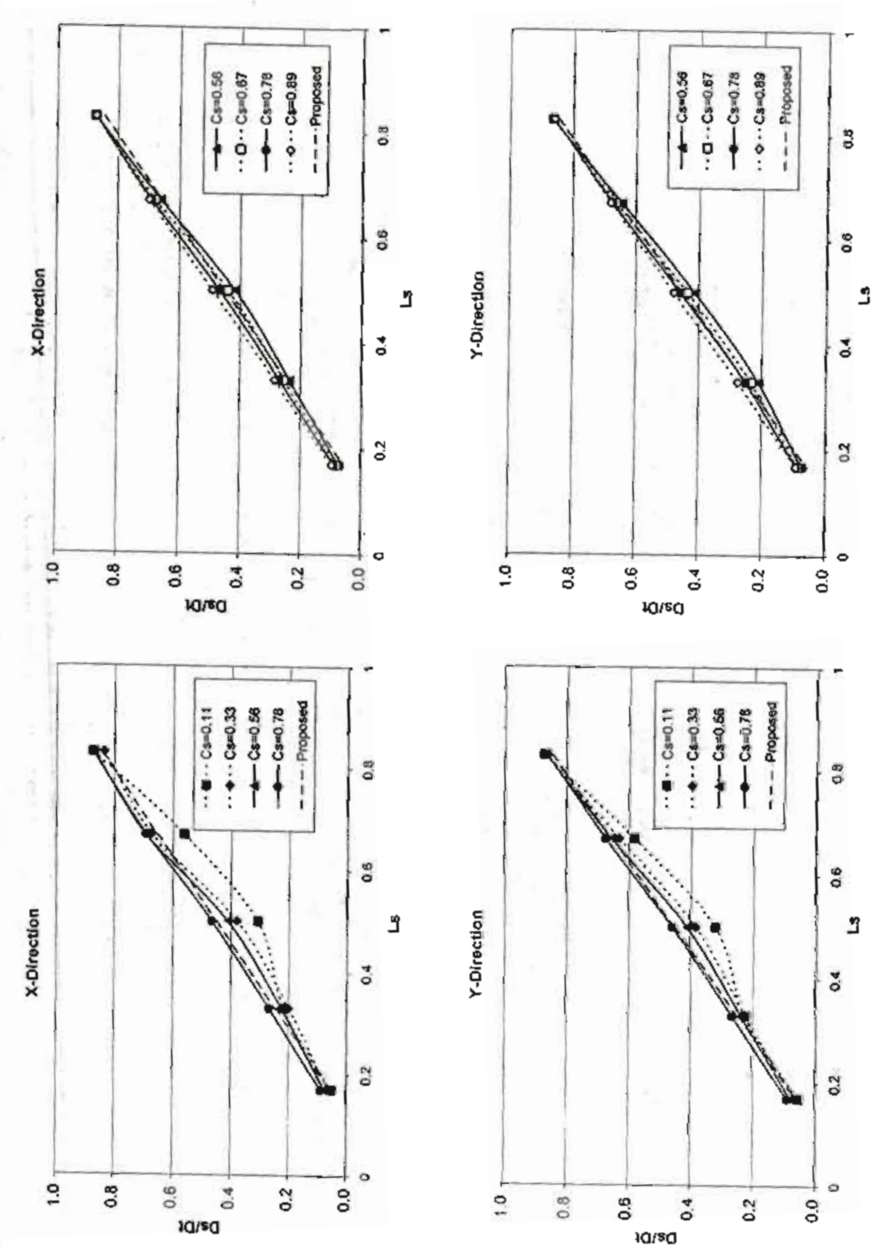
Unsymmetric Setback

Fig. (1) Configuration of Model Structures and Definition of Setback Parameters



(a) Symmetric Setback (b) Unsymmetric Setback

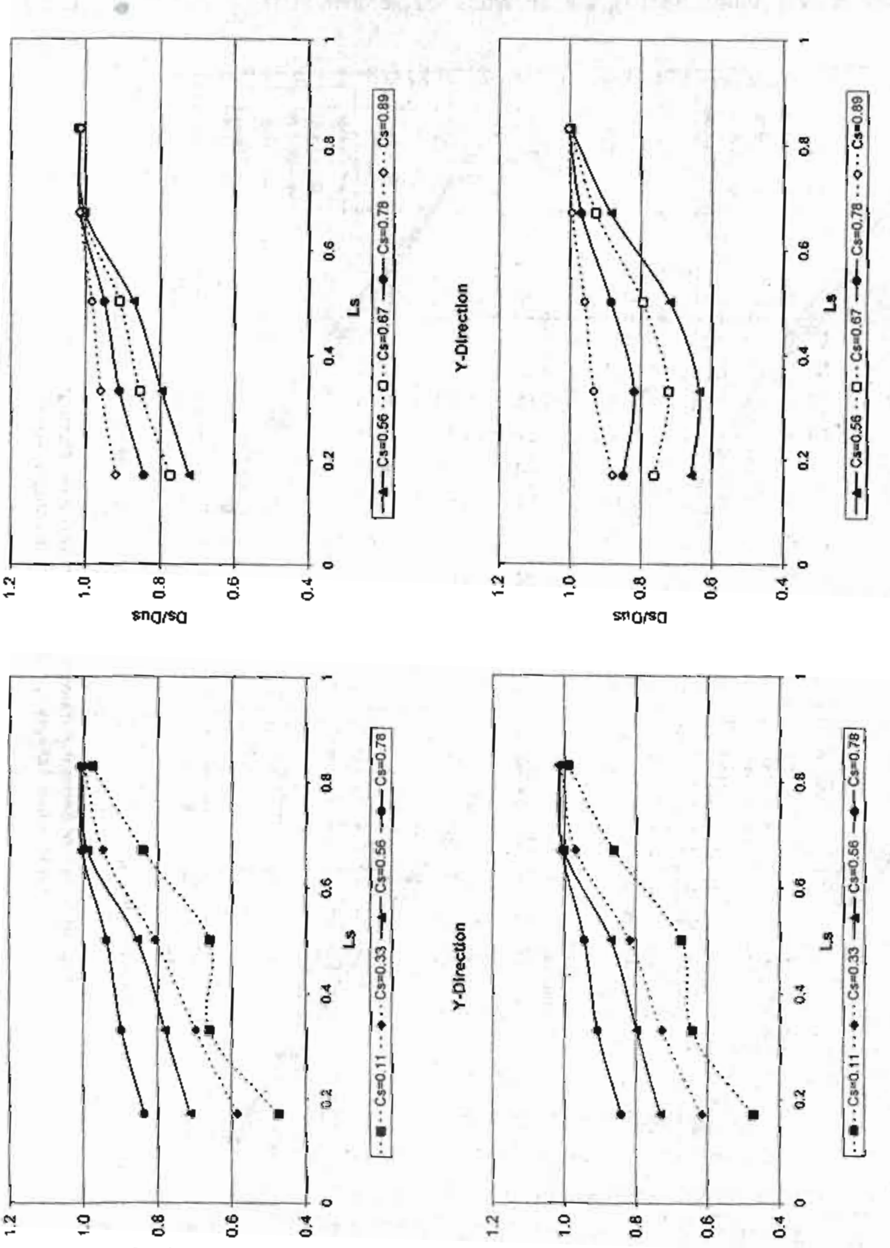
Fig. (2) Effect of Setback Parameters (Ls and Cs) on Structural Natural Periods



(a) Symmetric Setback

(b) Unsymmetric Setback

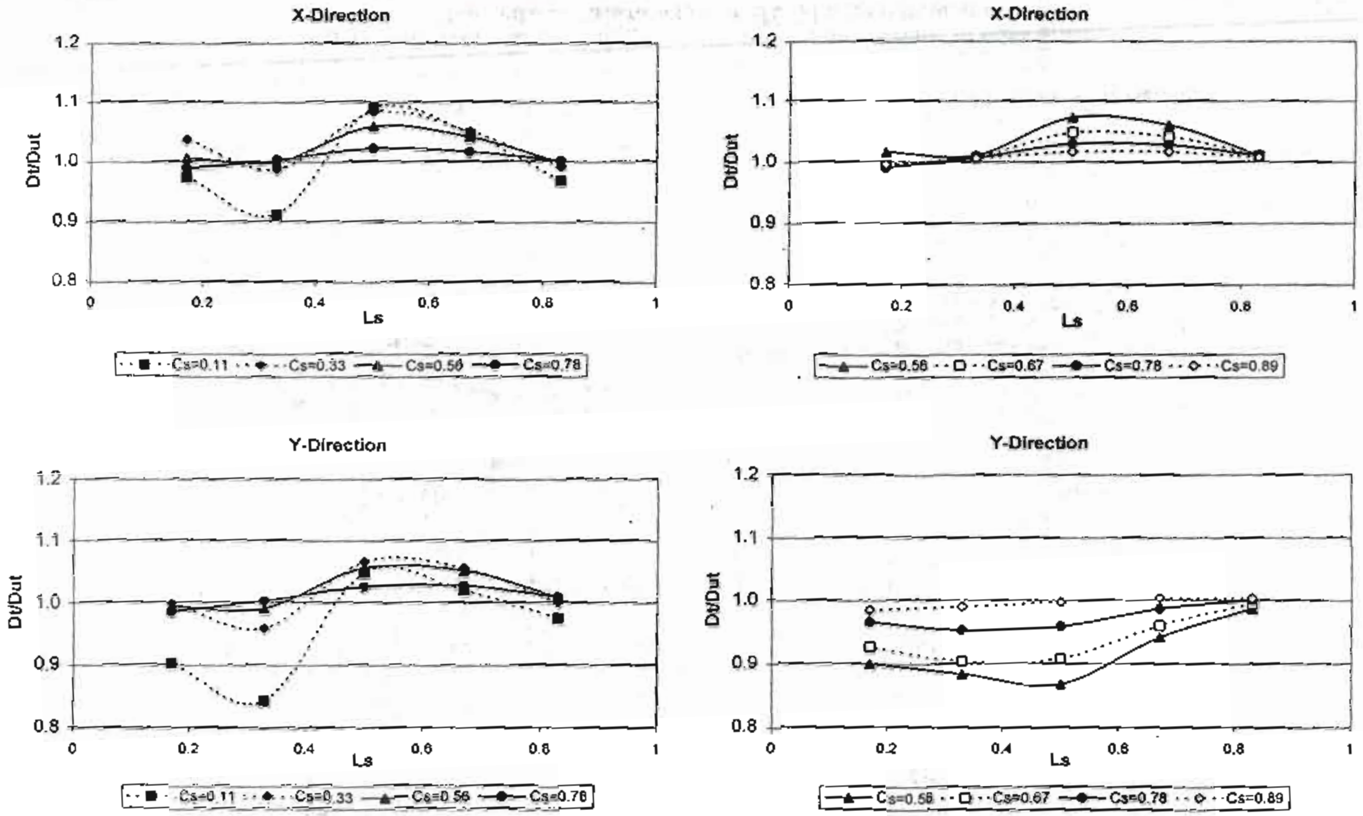
Fig. (3) Effect of Setback Parameters (Ls and Cs) on the Ratio of Setback Level Displacement to Top Story Displacement



(a) Symmetric Setback

(b) Unsymmetric Setback

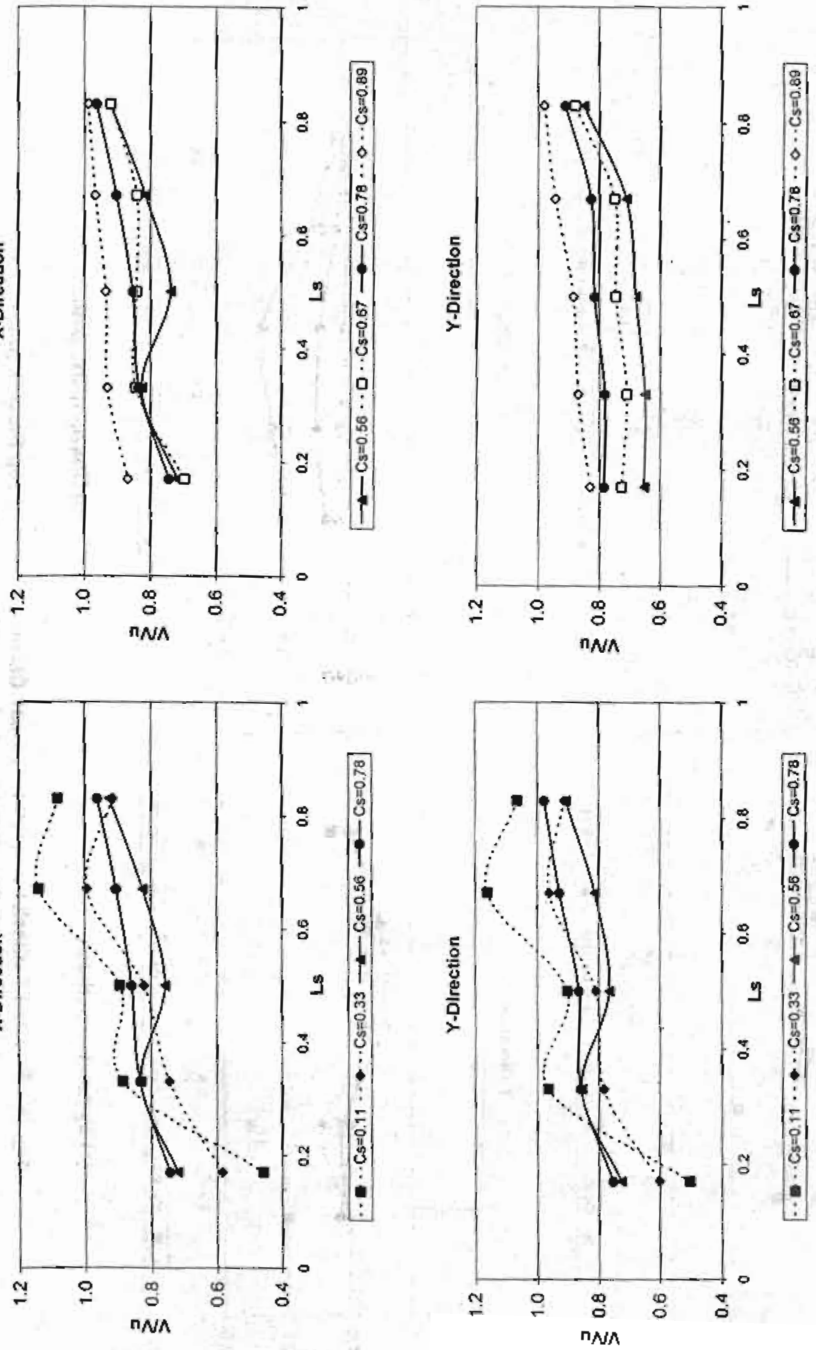
Fig. (4) Effect of Setback Parameters (Ls and Cs) on the Ratio of Setback Displacement to the Corresponding Displacement in the Uniform Structure



(a) Symmetric Setback

(b) Unsymmetric Setback

Fig. (5) Effect of Setback Parameters (Ls and Cs) on the Ratio of Top Story Displacement of the Setback Structure to that of the Uniform Structure



(a) Symmetric Setback

(b) Unsymmetric Setback

Fig. (6) Effect of Setback Parameters (Ls and Cs) on the Ratio of Base Shear of the Setback Structure to that of the Uniform Structure

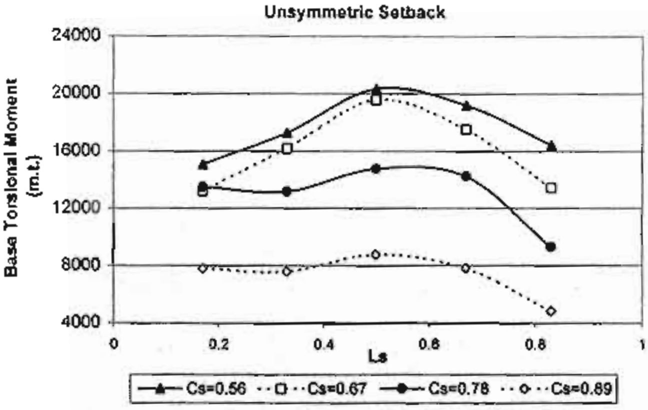
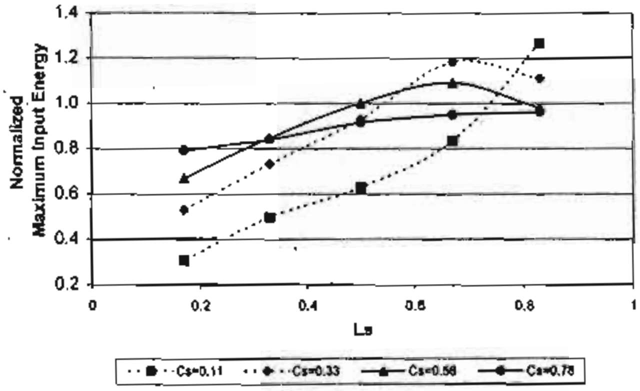
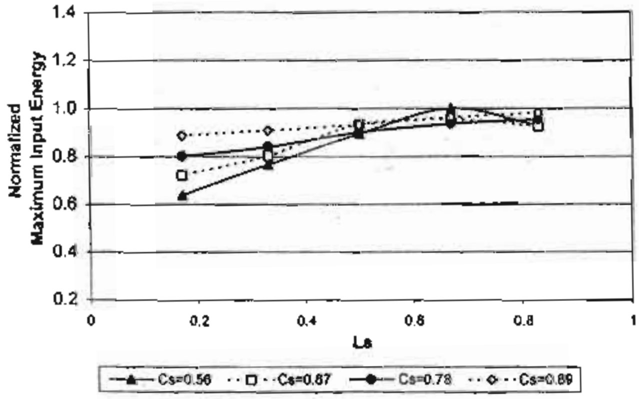


Fig. (7) Effect of Setback Parameters (Ls and Cs) on Base Torsional Moment



(a) Symmetric Setback



(b) Unsymmetric Setback

Fig. (8) Effect of Setback Parameters (Ls and Cs) on the Ratio of Maximum Input Energy of the Setback Structure to that of the Uniform Structure