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Experimental Estimation of Period of Vibration for Multistory RC Frame Buildings.

G. Mamaeva
Assistant Professor., Moscow Central Institute of Scientific Investigations of Structures., Russia Fed..

Hamdy El-gohary
Associate Professor., Textile Engineering Department ., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.

EXPERIMENTAL ESTIMATION OF PERIOD OF VIBRATION FOR MULTISTORY RC FRAME BUILDINGS

التقدير العملي لزمن الذبذبة للمنشآت الاطارية من الخرسانة المسلحة

Mamaeva G. V. *
Hamdy El-gohary **

ملخص البحث

تقدم الكودات العالمية معادلات وضعية لحساب زمن الذبذبة الأساسية للمنشآت متعددة الطوابق بنظام الاطارات الخرسانية المسلحة. القيمة الناتجة لزمن الذبذبة الأساسية من هذه المعادلات تختلف في كثير من الأحيان عن القيمة الفعلية وذلك لإهمال هذه المعادلات لعوامل هامه تؤثر في زمن الذبذبه.

في هذا البحث تم عمل تحليل لتسجيلات محطة خدمات الهندسة الزلزالية والمثبت أجهزتها في مجموعة من المنشآت القائمة والمستخدم فيها نظام الاطارات الخرسانية المسلحة. هذه المنشآت متعددة الطوابق ومقامة على تربة تأسيس مختلفة الخواص. تم استنتاج معادلات وضعية لحساب زمن الذبذبة الأساسية لهذا النوع من المنشآت مع الأخذ في الإعتبار نوعية التربة وأبعاد المنشأ في المسقط الأفقي.

ABSTRACT

At the present time most current building codes specify equations to be used for the calculation of the base shear and lateral loads. For the determination of these lateral loads, it is necessary to determine first the period of vibration of the building. As is known, the period of vibration of buildings can be determined theoretically or experimentally. The theoretical design values of the period of vibration are different from the experimental ones. Significant differences have been observed for RC multistory frame buildings and in a lesser degree for other building types such as: masonry, stone, large-paneled, and large-beams buildings.

The natural periods of vibration of 53 multistory RC frame buildings have been measured by the station of Engineering-Seismometeric Services (ESS). These 53 buildings have different number of stories, different dimensions in plan (with different plan length to width ratios) and erected on different soil conditions. On the basis of these data an improved simple empirical equation relating the period of vibration and the number of stories of the building is proposed to estimate the fundamental period of vibration of RC multistory frame buildings. In this paper the effect of soil condition and the dimensions of the building in plan on the period of vibration have been studied.

Comparison of periods determined using the proposed relationships and the adopted ones shows rather well agreement.

*Assistant Prof. Moscow Central Institute of Scientific Investigations of Structures, Russia Fed..

** Associated Prof. Faculty of Engineering – Mansoura University, Egypt.

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INTRODUCTION

At the present time most current building codes specify equations to be used for the calculation of the base shear and lateral loads. For the determination of these lateral loads, it is necessary to determine first the period of vibration of the building. As is known, the period of vibration of buildings can be determined theoretically or experimentally. The theoretical values of the fundamental period of vibration can be determined using empirical formulae recommended by the codes. Building codes provide empirical formulae that depend on the building material, building type and overall dimensions. In addition to codes empirical formulae, many researchers proposed empirical equations. These proposed equations have been obtained based on the analysis of experimental or analytical results. Some of these proposed equations which are based on experimental results, have been evaluated in this paper.

The theoretical design values of the period of vibration are different from the experimental ones. Significant differences have been observed for RC multistory frame buildings and in a lesser degree for other building types such as: masonry, stone, large-paneled, and large-beams buildings.

The value of the period of vibration is not constant for real buildings. In the serviceability period of buildings, deformations in building elements take place such as: settlement of foundation, appearance of microcracks and macrocracks related to vibrating excitation due to seismic actions or other different artificial processes. So, as a result, these excitations cause changes in building rigidity and consequently in its period of vibration. Results of Engineering Seismic observations show that periods of 5 to 9 stories frame buildings, after 30 seismic excitations with intensity ranged from 3 to 5 degrees, increase by 10-20% comparing with periods recorded before these earthquakes [6].

The natural periods of vibration of 53 multistory RC frame buildings in MOSKO have been measured by the station of Engineering-Seismometeric Services (ESS) [8]. These 53 buildings have different number of stories, different dimensions in plan (different plan length to width ratios) and are erected on different soil conditions. This collected data made it easy to study the effect of each of the building height, the dimensions of building in plan and the soil condition on the fundamental period of vibration.

The objective of the present paper is to determine an improved simple empirical equation which relates the period of vibration and the number of stories of the building in order to estimate the fundamental period of vibration of RC multistory frame buildings. In this paper the effects of soil condition and the dimensions of the building in plan on the period of vibration have been studied.

CODE EQUATIONS AND PROPOSED EMPIRICAL FORMULAE

For the determination of the period of vibration in various current Codes and also by the recommendations of many researchers [1, 2, 4, 6], empirical equations relating the period of vibration T and the number of stories of the building N (or overall building height H) are recommended for multistory RC frame buildings. These recommended formulae are often used to determine the fundamental period of vibration for design purposes. Most of these equations were obtained based on periods of buildings measured from their motions recorded during earthquakes or in tests carried out on prototypes.

For the purpose of comparison, the formulae recommended in some of the current codes and equations obtained previously by Polyakov (1969) (equation (1)) [7], Blinnikova-Vyaemskaya (1974) (equation (2)) [1], Crowley and Pinho (2006) (equation (3) for longitudinal direction and equation (4) for transverse direction) [2], Goel and Chopra (1997) (equation (5) for longitudinal direction and equation (6) for transverse direction) [5], in addition to Egyptian Code equation (7) [3], UBC and Eurocode (equation(8)) [4, 11], were considered. These equations have the forms:

$$T = 0.068 \cdot N + 0.05 \tag{1}$$

$$T = 0.07 \cdot N \tag{2}$$

$$T_l = 0.052 \cdot H^{0.9} \tag{3}$$

$$T_t = 0.075 \cdot H^{0.9} \tag{4}$$

$$T_l = 0.042 \cdot H^{0.92} \tag{5}$$

$$T_t = 0.0507 \cdot H^{0.92} \tag{6}$$

$$T = \frac{0.0905 \cdot H}{\sqrt{B}} \tag{7}$$

$$T = 0.075 \cdot H^{0.75} \tag{8}$$

Where

N Number of stories,

H Building height in ms,

B Building width in ms.

It is clear that all these equations relate the building fundamental period of vibration T to the number of stories N (or building overall height H) without consideration of the effect of soil conditions. The effect of building dimensions in plan appears in equation (7) in the form of square route of building width in the considered directions. Both Blinnikova-Vyaemskaya (1974) and Goel and Chopra (1997) recommend separate equations for periods in longitudinal and transverse directions. These equations give shorter vibration periods in longitudinal direction than in transverse direction ($T_L \approx 0.7\ T_V$ according to equations (3) and (4) and $T_L \approx 0.83\ T_V$ according to equations (5) and (6)).

The use of the previous formulae gives the value of the period of vibration without the consideration of the effect of some important factors such as: variations in foundation soil conditions and geometric dimensions of the building in plan. Figure (1) shows the results obtained using the previous equations considering that the story height equals 3.0 ms for equations relating the period of vibration with building height thus, H= 3 N. In equation (7) the building width B was assumed 10 ms because this value of width gives nearest results to the periods obtained using equation (8). From Fig. 1 it can be noticed that both equations (1) and (2) give the shortest periods while equation (4) gives the longest ones.

ANALYSIS OF EXPERIMENTAL DATA

Aiming to determine relationships between period of vibration and the number of stories of multistory frame buildings with the consideration of soil conditions and dimensions of building in plan, the experimental values of the periods were analyzed. The source of these experimental data is the records of the station of Engineering – Seismometery Service (ESS) fixed in multistory frame buildings with different number of stories, different dimensions in plan and erected on foundation soils with various conditions [8], [9]. According to the Russian seismic code all kinds of soils are classified into three categories [10]. Soils related to the first category are all types of rocks, while the second category is related to gravel and sandy gravel whereas the third category is related to fine sand.

The methods of forced vibration considered for the experimental determination of the period of vibration are different: viz. by the records of micro-seismic, by the use of impulse actions or by the use of vibration machines. In all these methods the loading levels were controlled within the elastic range of the building behavior. The value of the period of vibration depends on the method of forced excitation. However, the effect of the method of excitation was not taken into the count.

For the analysis of the data obtained from records of ESS station, periods of vibration of 53 frame buildings with number of stories varied from 3 to 25 stories, having different dimensions in plan and erected on soils of categories, I, II and III were considered. The distribution of all the chosen buildings by the number of stories is as follow: 3; 4; 5; 7-8; 9-10; 11-12; 13-14; 15-16 and 18-25 stories. The number of the correspondingly buildings (m) equals: 3; 6; 9; 5; 10; 6; 3; 5 and 6. From the data shown it is clear that the maximum number of experimental results (70%) is for number of stories up to 12.

The relationship between the period of vibration and the number of stories is noticed to be linear. The coefficients in the equations were determined on the basis of the experimental results using the least squares method. At the beginning, all values of the period of vibration were considered independently on the building dimensions in plan and the soil category. When determining the relationship T-N for vibration in the lateral direction of the building, the values of the periods that significantly are less than the values of the periods in the longitudinal direction were excluded. This combination of periods corresponds to buildings with frequent distribution of lateral walls (for example, hotels, guest houses, hospitals, etc...). The following equations are proposed:

For longitudinal direction:

$$T_L = 0.0577 \cdot N + 0.05 \qquad (9)$$

For transverse direction

$$T_T = 0.06 \cdot N + 0.0567 \qquad (10)$$

Figure (2) shows the results of the proposed formulae (9) and (10) compared with the results obtained when using Egyptian Code equation (7) and UBC and Eurocode equation (8). From Fig. 2, it is clear that the proposed equations (9) and (10) give shorter periods than those obtained from Code equations (7) and (8).

The results obtained from equations (9) and (10) are also compared with the results obtained using the previously proposed formulae (equations (1) to (6)) as shown in Fig. 3. From this Figure it can be noticed that the periods obtained using equations (9) and (10) are smaller than all the periods obtained from previously recommended equations. Also equations (1) and (2) give periods close to those obtained from equations (9) and (10).

For the estimation of the effect of the soil category on the period of vibration of the building, the relationship T - N was determined separately for buildings erected on soils of categories, I, II and III. The equations proposed have the following forms:

For longitudinal direction

$$T_L = 0.0085 \cdot (S + 4.8) \cdot N + 0.025 \cdot S \qquad (11)$$

For transverse direction

$$T_T = 0.012 \cdot (S + 3) \cdot N + 0.06 \qquad (12)$$

Where

S is a factor referring to soil category (S=1; 2 and 3 for types I; II and III soil categories respectively). Equations (11) and (12) have the forms of equations (9) and (10) for the case when substituting for S = 2.

Figure 4 shows the results obtained using the proposed equations (11) and (12) for the periods of vibration in both longitudinal and transverse directions for the three soil categories. For buildings erected on soils of categories I and II, the differences between periods of vibration in longitudinal and transverse directions are relatively small, while in case of buildings erected on soils of category III the differences are noticeable. Also, the period of vibration increases with the increase of soil category (for category III it is longer than categories I and II), i.e., with the deterioration of soil mechanical properties the vibration period increases. From Fig. 4 it is clear that, the effect of soil properties is most noticeable for buildings with bigger number of stories.

EFFECT OF BUILDING DIMENSIONS IN PLAN

To study the effect of building dimensions in plan on its fundamental period of vibration, the ratio R of length L to width B in the plan (R = L / B) is considered. The effect of building dimensions in plan is studied first for buildings erected on soils of category II; because these buildings have the maximum number of experimental data.

The experimental relationships T-R are shown in Figs. 5 and 6 for longitudinal and transversal directions, respectively shown as dotted lines for buildings with number of stories 5; 10; 15; 20 and 25. Considering T-R relationships obtained using the experimental data, it can be concluded that the period of vibration of building frames for all number of stories can be considered constant for values of R = 1 to 3. Increasing R from 3 to 4; the building period of vibration decreases. The effect of building dimensions in plan is mostly perceptible for buildings with larger number of stories. Values of periods for R > 4 can be considered as constant. The shown experimental relationships allow classifying buildings according to the ratio R into short-plan (R ≤ 3) and long-plan buildings (R > 4). Based on this classification the following T-N relationships have been proposed for buildings erected on soils of the category II:

For longitudinal direction

For R ≤ 3

$$T_L = 0.058 \cdot N + 0.08 \qquad (13)$$

For R ≥ 4

$$T_L = 0.047 \cdot N + 0.1 \qquad (14)$$

For transverse direction

For R ≤ 3

$$T_V = 0.061 \cdot N + 0.05 \qquad (15)$$

For R ≥ 4

$$T_I = 0.054 \cdot N + 0.09 \qquad (16)$$

The plotted curves using the proposed equations (13) to (16) for T-R shown as solid lines agree very well with the experimental results (dotted lines), for both longitudinal and transversal directions as shown in Figs. 5 and 6. For buildings in which the ratio R has intermediate values between 3 and 4, the periods of vibration can be determined by linear interpolation.

The relationships T-R shown in Figs. 5 and 6, allow making a basic conclusion that the periods of vibration of long-plan buildings and short-plan ones in longitudinal direction are essentially distinguished among themselves, but in transverse direction the differences are smaller.

Classification of buildings according to their dimensions in plan allows determining the relationship T-N for short-plan and long-plan buildings, erected on soils of I and III categories. The general forms of the relationships between the fundamental period of vibration and the number of stories for RC multistory buildings with the consideration of the effects of both soil category and building dimensions in plan are as follow:

For longitudinal direction:

For R ≤ 3

$$T_L = 0.0115 \cdot (S + 3) \cdot N + 0.09 \qquad (17)$$

For R ≥ 4

$$T_L = 0.0056 \cdot (S + 6.3) \cdot N + 0.045 \cdot S \qquad (18)$$

For transverse direction:

For R ≤ 3

$$T_V = 0.0121 \cdot (S + 3) \cdot N + 0.055 \qquad (19)$$

For R > 4

$$T_F = 0.012 \cdot (S + 2.3) \cdot N + (0.12 - 0.01 \cdot S) \quad (20)$$

A comparison of building vibration periods calculated using these general recommended equations for different soil categories is shown in Fig. 7 for longitudinal direction and in Fig. 8 for transversal direction.

The effect of the building dimensions in plan with length to width ratio (R = L / B) ranging from 3 to 4 is greater in longitudinal direction than in the transverse direction. In case of vibration in the longitudinal direction, the slope of curves for this portion is greater than in the case of vibration in transverse direction. This slope increases with the increase of the number of stories.

Although the relationships T-N are determined based on different numbers of experimental results m, the effect of soil category and building dimensions in plan on the value of the period of vibration is appreciable. Lowering of soil category (properties) increases the period of vibration. Soil categories show a large scale effect on the period of vibration of short-plan buildings than on the long-span ones. Building dimensions independently of soil category nearly do not show any appreciable effect on the period of lateral vibration.

Effect of the number of stories on the period of vibration of short-plan and long-plan buildings is different. Angle of slope of the relationship T-N for short-plan buildings is greater than that for long-plan buildings. Soil category has large scale effect on the period of vibration of short-plan than the long-plan buildings. Maximum periods of vibration characterize short-plan buildings with high number of stories, erected on soils of category III (see Fig. 9).

CONCLUSIONS

For the determination of buildings periods of vibration it is necessary to take into consideration the effect of soil category and the building dimensions in plan. Neglecting these two factors may lead to significant underestimation or overestimation of the period of vibration of buildings particularly for buildings with bigger number of stories.

Based on experimental data, empirical equations are proposed for the determination of the fundamental period of vibration of multistory RC building frames with the consideration of the effects of both soil foundation conditions and building dimensions in plan.

The experimental data allow classifying buildings according to their dimensions in plan (ratio R = length / width) into short-plan (R ≤ 3) and long-plan buildings (R ≥ 4).

With the use of the proposed empirical relationships, periods of longitudinal vibration of long-plan and short-plan buildings with number of stories ranging from 3 to 25 with the consideration of the effects of dimensions in plan and soil category can be determined. Comparison of periods determined using the proposed relationships and the adopted ones [2, 3] shows rather well agreement only for buildings of short-plan type erected on soils of category II.

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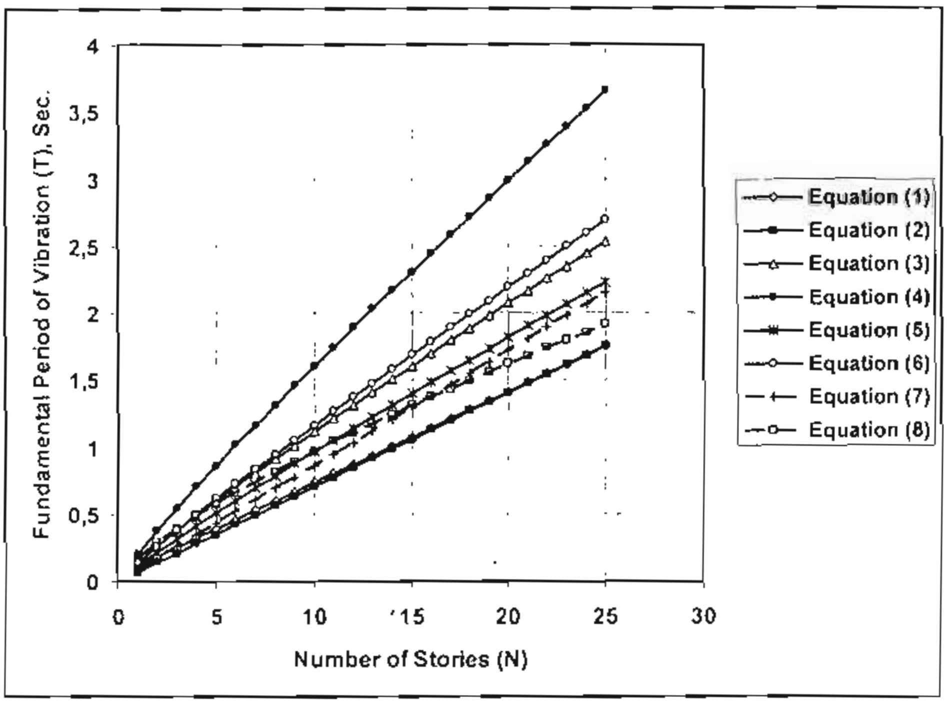

Fig. 1 Results of Empirical Formulae and Code Equations

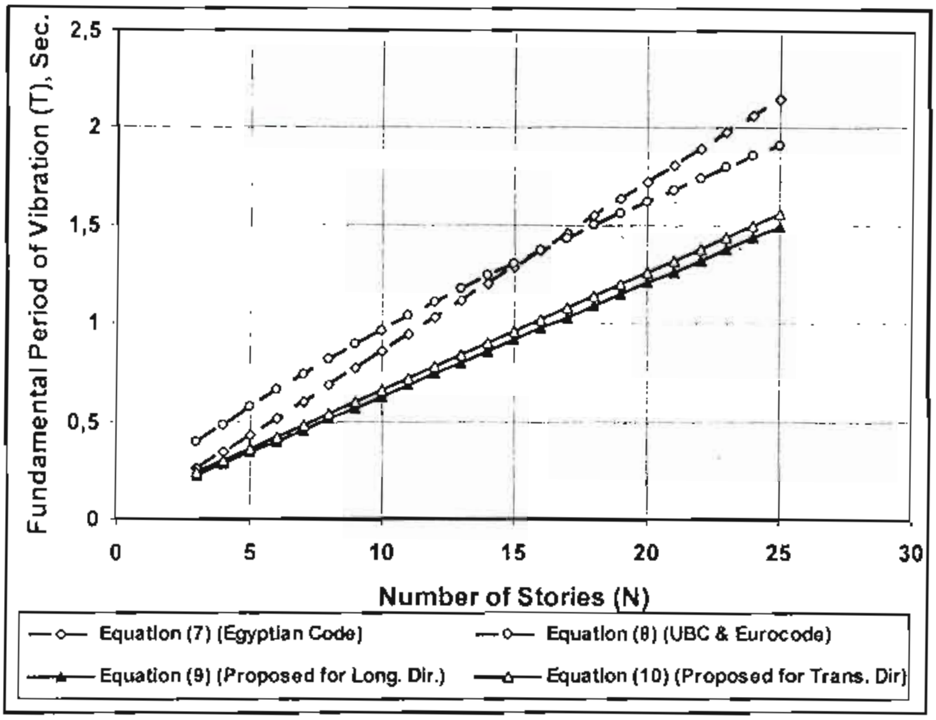

Fig. 2 Results of code equations and first proposed formulae

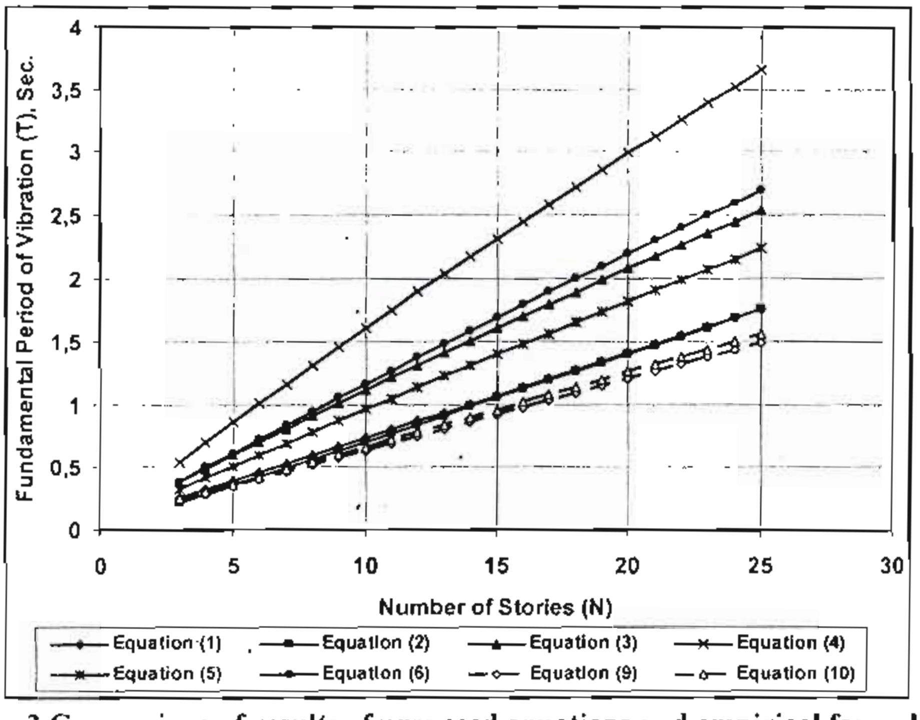

Fig. 3 Comparison of results of proposed equations and empirical formulae

EFFECT OF FOUNDATION SOIL

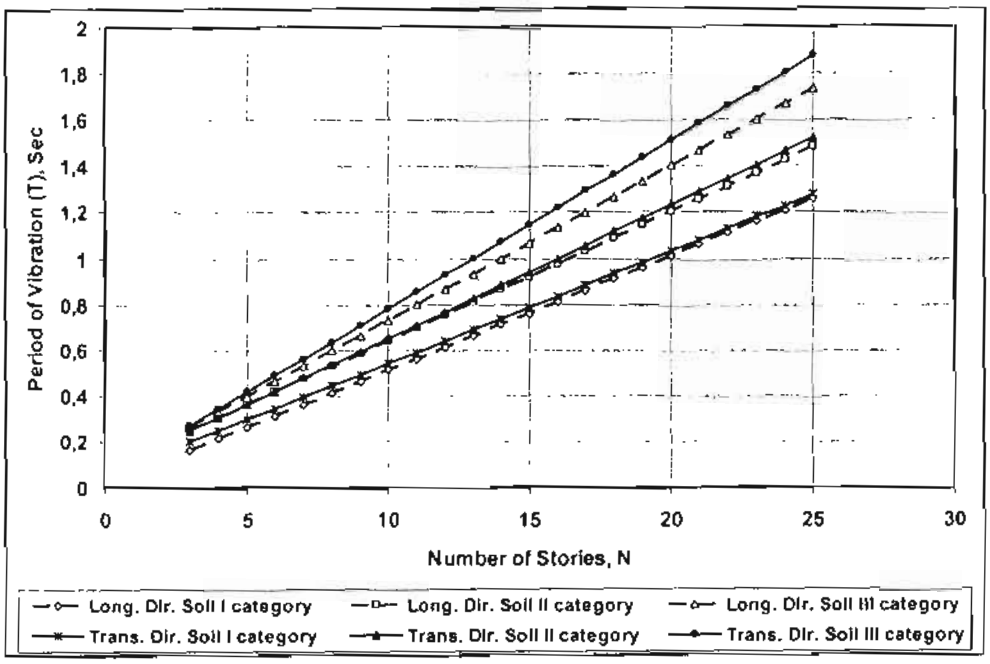

Fig. 4 Effect of soil category on the period of vibration

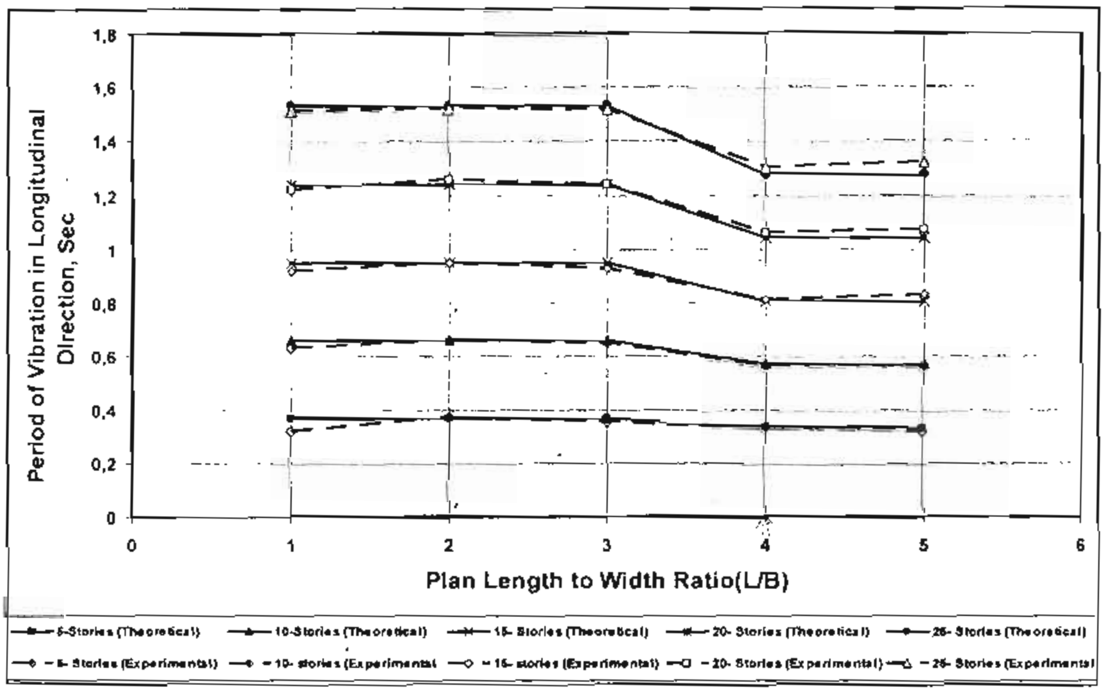

Fig. 5 Effect of building dimensions on the period of vibration in longitudinal direction

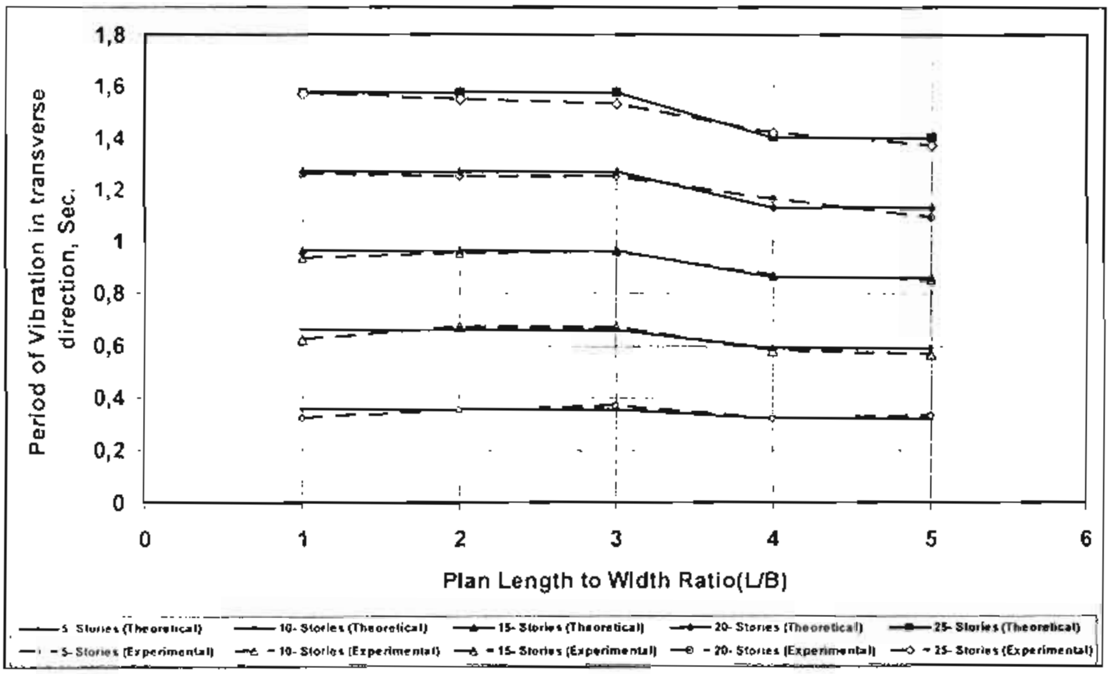

Fig. 6 Effect of building dimensions in plan on the period of vibration in transversal direction

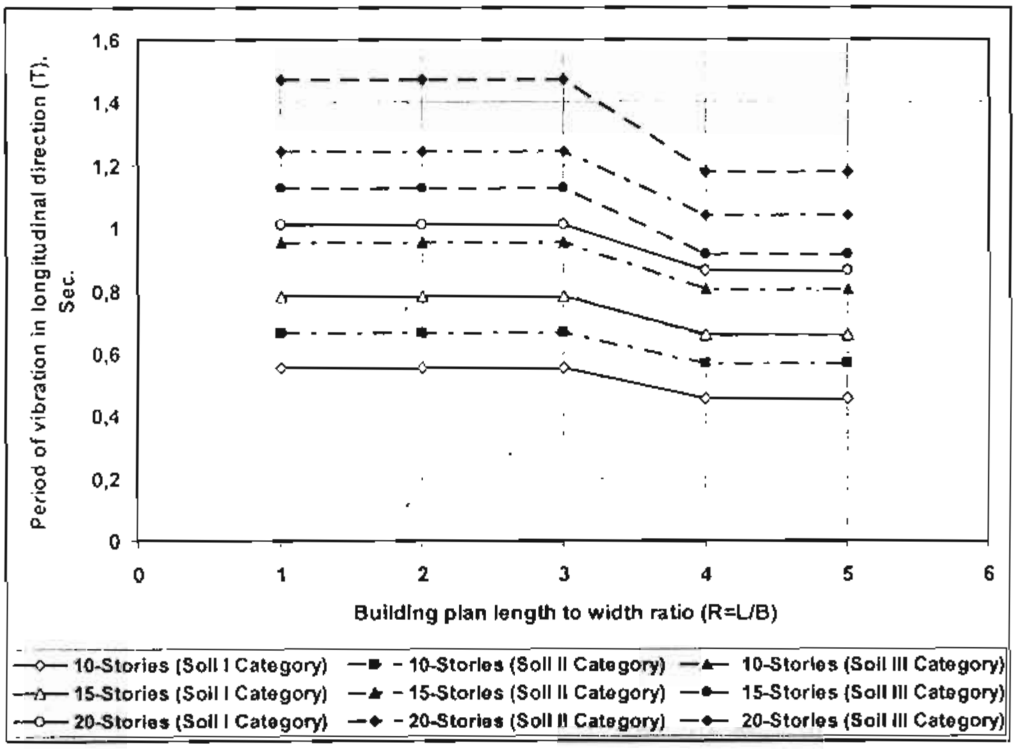

Fig. 7 Effect of building dimensions in plan on the period of vibration in longitudinal direction for different soil categories

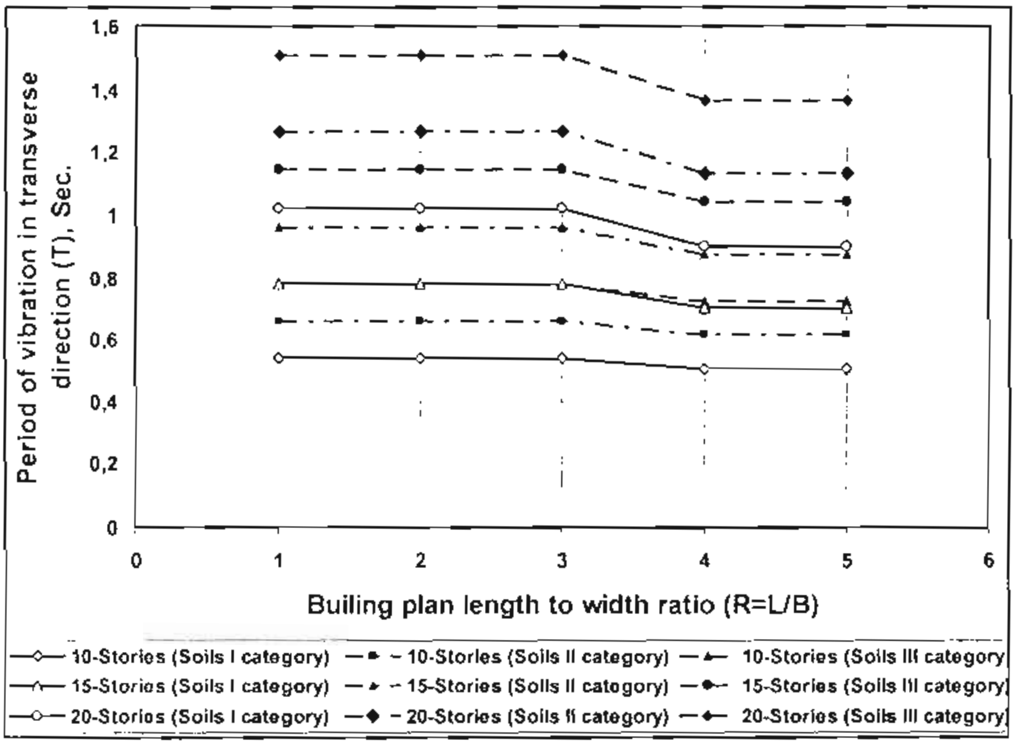

Fig. 8 Effect of building dimensions in plan on the period of vibration in transverse direction for different soil categories

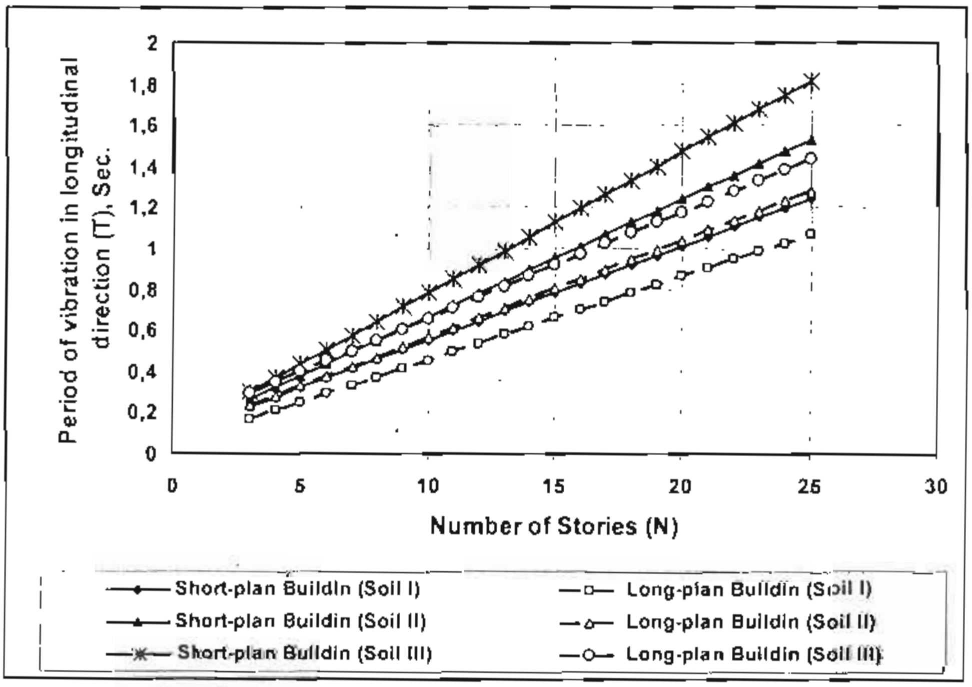

Fig. 9 Period of vibration for Short-plan and Long-plan buildings