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Parametric investigation on structural behaviour of single and multistory system during shock (displacement, acceleration, frequency, impact force ..)

M.BENSAFI*, G. PIRONNEAU†

*Department of Civil Engineering, University of Science and Technology of Oran Bp 1505 Oran Algeria.
†Department of Civil Engineering, Central School of Nantes, 1 rue de la Noe 44072 Nantes France

ABSTRACT

Considering the small space between adjacent buildings, shocks may occur during earthquake. The induced impact forces, will be added to those induced by the earthquake acceleration. The laters often provide distribution of stress and displacement not taken into account in the basic design.
Severe damage and even collapse of the structure occuring under the earthquake effects can be attributed to this effect, engineers usually manage to foresee a calculed interval derived from the existing design rules.
However use of calculating forms is relatively uncertain owing to a lack of adequate parameters on shock behaviour.
A parametric investigation has enabled us to study the behaviour of structures at one or several levels (displacement, acceleration, frequency, impact force..)
A numerical method has been developped ; the shocks are simulated by linear visco-elastic impact element (spring- dashpot).
The impact of structures which collapse as well as the interacting problem of soil structure have not been considered in this study.

KEYWORDS

Buildings, shocks, gaps, earthquakes, impacts, structure, non-linear.

INTRODUCTION

In building construction, the use of new materials one the one hand, and the increase in the number of levels on the other, require a deeper approach of the problems concerning resistance and stability.
Actually, the main preoccupation is to develop research in the paraseismic field, in order to know the effects due to the earthquakes better, and consequently arrive at a better conception of construction work.
An earthquake causes horizontal and vertical displacement of the structures, the gap between adjacent structures having insufficient width causes mutual pounding thus leading to : pounding between structures of different heights which lead to an amplification of upper floor - movement, and consequently a collapse of the upper part of the biggest structure, due to gravitational effects ; shearing failure of columns by a floor ; disorder in the masonry ; cracks in the lintel etc...

The numerical results presented herein, are related to a structure of one, or several levels which, under the effect of a harmonique movement of the soil $X_S(t)$, causes shocks against very stiff wall. As the wall is supposed to displaced with the soil under $X_S(t)$, only the structure deforms to cause impact against the impact wall.

STRUCTURE DESIGN WITH THE IMPACT WALL

The behaviour of columns, beams and concrete wall is supposed to be elastic and the floors are assumed to have an infinitely stiffness in their plan. The real structure is thus replaced by a system of vertical elements braced in the same way, and connected to all floors by means of inertia strut to the two ends. The masses are applied to each floor. The impact wall is assumed to displace in phase with the ground, only the structure will deform to induce the shocks against the impact wall.With $X_s(t)$: displacement of ground, and U : relative displacement of the structure

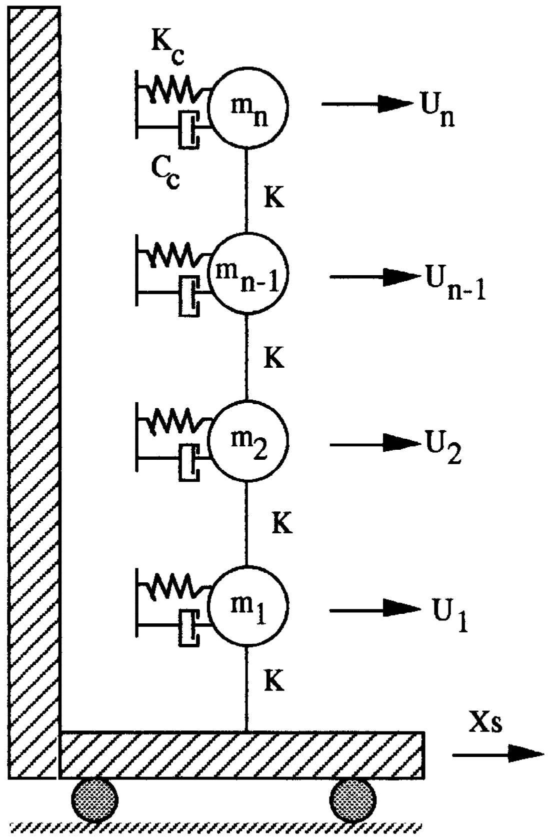


Fig.1: Design of the structure and the impact wall.

FORMULATION OF EQUATIONS

With no Contact :

The relation between displacememt can be written as: $U = X - X_s$.

For an harmonic excitation of a ground $X_s = Xs_o \mathrm{Sin}\omega_s t$, and if the proper damping of the structure is taken into account ; with $\{b^T\} = (1,1,1,..............1)$, the equation of the movement is :

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = -[M]\{b^T\}\{\ddot{X}_s\} \tag{1}$$

During the Impact :

When the displacememt U is greater than the gap size E, the spring representing the impact elememt is actived. The energy released due to the vibration is realised by dashpot C and by an introduction of an additional dashpot C_c , with $C' = C_1 + C_2 + C_c$ and $K' = K_1 + K_2 + K_c$, the equation will be :

$$[M]\{\ddot{U}\} + [C']\{\dot{U}\} + [K']\{U\} = -[M]\{b^T\}\{\ddot{X}_s\} \tag{2}$$

INFLUENCE OF VARIOUS PARAMETERS

Mass Influence

A study of mass influence has allowed us to show that greater amplification responses were obtained for increased excitation frequencies and that if one wanted to avoid them, it was sufficient to have regular structures with ratio between floor masses in addition their over loads, and bearing elements of order 1/9 to 1/10 for a SDOF see fig 2 and 1/8 to 1/9 for structures of MDOF see fig 3.

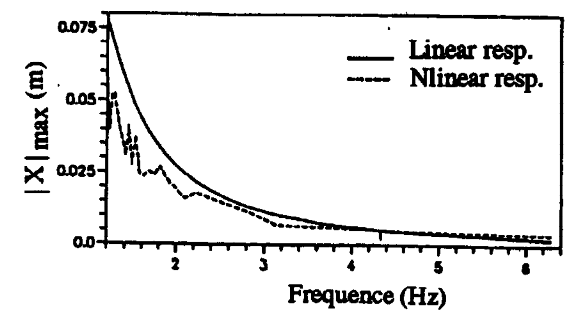


Fig.2 : Displacement versus fundamental frequency for a SDOF with variable mass, $E = 0$, $K_c = K_l$.

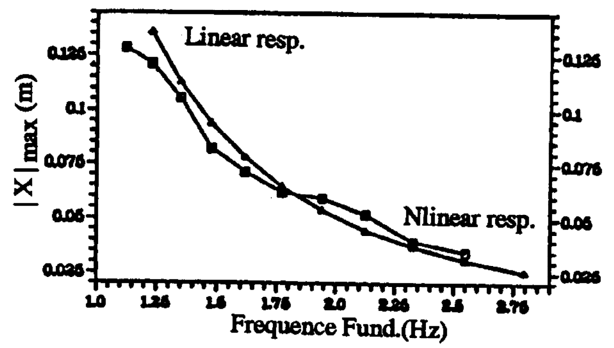


Fig.3 : Displacement versus fundamental frequency of the 3 rd level. with $E = 0$, $K_c = 60$ K.and variable mass.

Influence Of The Gap Size

The influence of the gap size has enabled us to make the following conclusions : for a SDOF the increase of joint dimension implies a reduction in the number of impacts, and an amplification in response when we choose a damping null. When the damping ratio is superior or equal to 5% and the excitation frequency in proximity to the natural frequency, the response varies only slightly; But for an excitation frequency different from the natural frequency, we noticed a decrease in impacts and increase in response.

For a system of MDOF as for a SDOF, the increase of joint dimension brings a decrease in number of impacts. Shock influence is greater on lower levels, we also notice that a greater amplification in the movements of the 3 levels. We observed for an excitation frequency in proximity to the fundamental frequency, the movement is highly reduced. Considering these previous conclusions, it would be desirable to choose an optimal joint dimension, which would diminish impact number, but moreover reduce amplification, see fig 4 and 5.

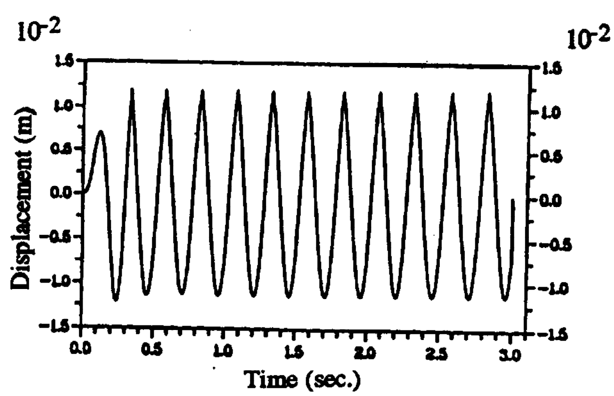


Fig.4 : Displacement versus Time with shock, for a SDOF, $K_c = 170$ K, $\xi = 10\%$, $f = 4$ Hz.

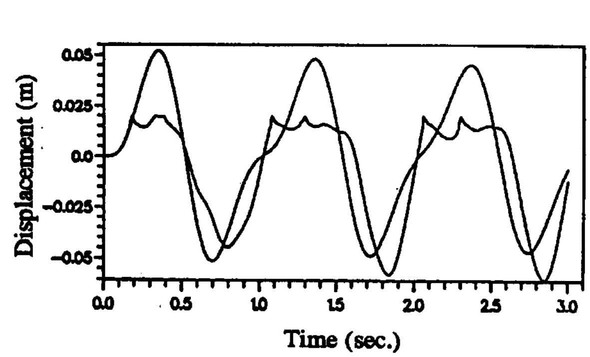


Fig.5 : Displacement versus Time with and without shock, of the 3 rd level, $f = 1$ Hz, $E = 0.02$m, $K_c = 16$ K.

Influence Of Impact Stiffness

As for the impact stiffness, its variation inform us on various constitutive materials. For a one level structure, displacements are less sensitive to variations, an amplification is certainly observed, but it does not increase much when stiffness increases; however we notice that shocks become harder. For a structure with several levels the verifications differ, the influence of impact rigidity variation is fairly important. For a fairly weak stiffness (4K) the response after shock is quite regular ; for an impact rigidity less weak (16K) we notice that the response after the first shock is smaller than the linear response amplifying after. When the impact rigidity increases, either the shock occurs only on the last level or on the 2 rd and 3 rd levels; it is the opposite which occurs for the response after the 1 st shock in relation to the example where rigidity impact is weak, that is that the response after shock amplifies to diminish after. It even goes below the linear response (for an impact rigidity average 60K), when the shock takes place only on the last level . Displacements undergo the variation influence of impact rigidity, and this influence is evermore important when the impact rigidity is big, which leads to a drastic influence on the structure itself, and what it contains, due to the interaction between different levels. To reduce this influence we have one single remedy, use the joint dimension in such a way as to diminish amplification of responses and number of shocks on the different levels; and consequently the resulting interaction see fig 6 and 7.

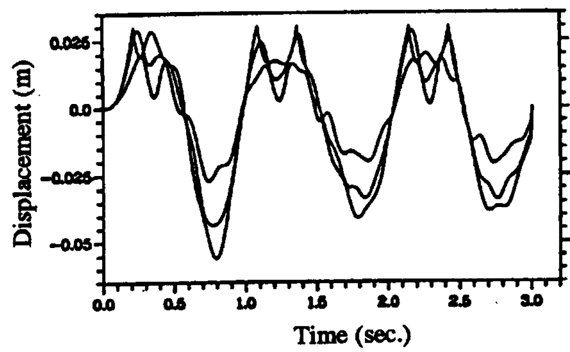


Fig.6 : Displacement versus Time with shock of the three levels, $K_c = 60$ K, $\xi = 5$ %, E = 0.03m, f = 1 Hz.

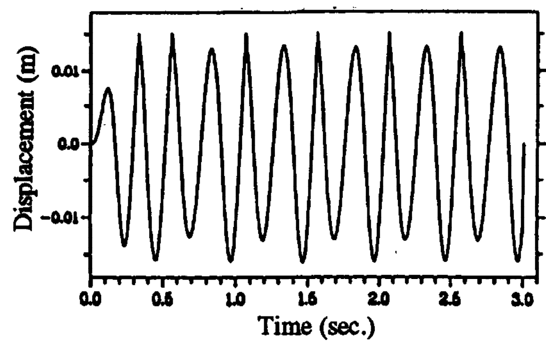


Fig.7 : Displacement versus Time with shock, for a SDOF, $K_c = 60$ K, $\xi = 5$ %, E = Xmax/2, f = 4 Hz.

Joint Dimension Influence And Impact Stiffness On Acceleration

For acceleration, we have noticed that shocks generated very important accelerations with instantaneous variation. Whatever system considered, the acceleration increases with joint dimension and with impact rigidity. you will note the influence of shock on the acceleration at lower levels are fairly considerable even when those do not undergo shock, see fig 8 and 9.

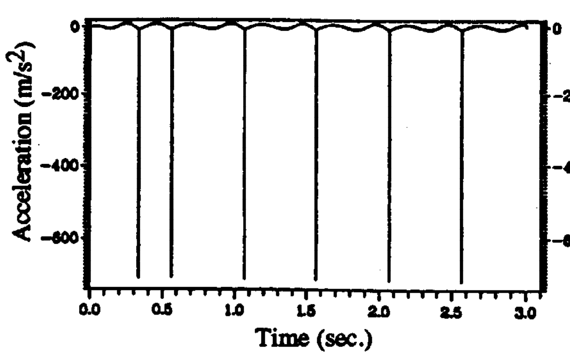


Fig.8 : Acceleration versus Time for a SDOF after shock, $K_c = 60$ K, $\xi = 5$ %, E = Xmax/2, f = 4 Hz.

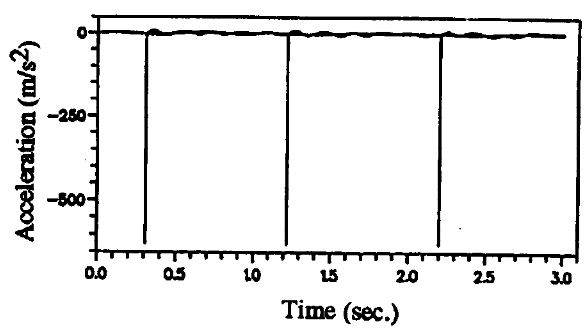


Fig.9 : Acceleration versus Time of the 3 rd level after shock, $K_c = 16$ K, f = 1 Hz, E = 0.05m, $\xi = 5$ %.

Excitation Influence On Accleration

In case of shock for a one single level structure, we notice the appearance of peaks in the proximity of structural natural frequency and multiple frequencies. when the impact rigidity increases, these peaks come with a certain shift to the right.
For a system of MDOF the biggest peak appears neighbouring the fundamental frequency, other smaller peaks appear in the neighbourhood of other natural frequencies. When the impact rigidity increases, the peaks are much bigger with a certain shift in relation to the natural structural frequency ; moreover we notice peaks appear for frequencies less than the fundamental frequency, see fig 10 and 11.

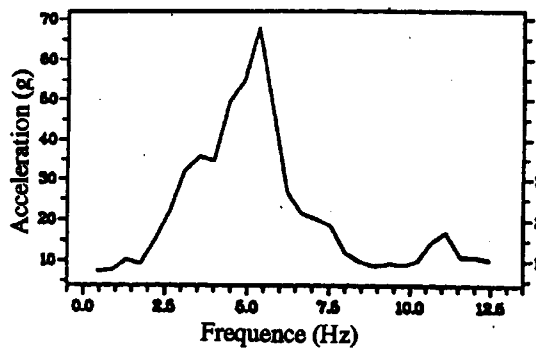


Fig. 10 : Acceleration versus frequency of a SDOF, $K_c = 60$ K, $\xi = 5$ %, E = 0.

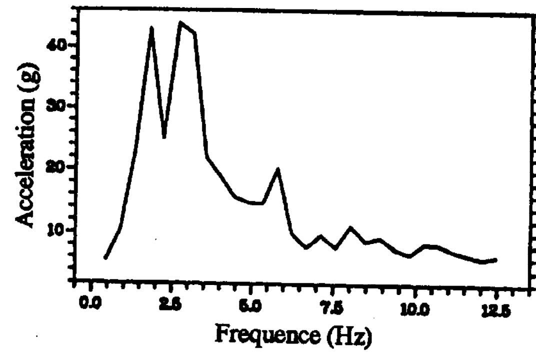


Fig. 11 : Acceleration versus frequency of the 3 rd level, $K_c = 20$ K, $\xi = 5$ %, E = 0.

Impact Forces

For a system of SDOF, shock forces increase with impact rigidity and joint dimension. Maximum impact force is obtained for an excitation frequency equal to the natural structural frequency. The same conclusions have been made for a system of MDOF. However one remark must be made, beyond a certain joint dimension, impact force no longer increases ; this observation is certainly valable for both types of system. Thus we defined a criteria to determine maximal impact force ; for that we take into account in calculating an excitation frequency equal to the fundamental frequency and an optimal joint dimension. The superposition of this forces to the seismic excitation will enable us to foresee structure dimensions which would undergo collision, see fig 12 and 13.

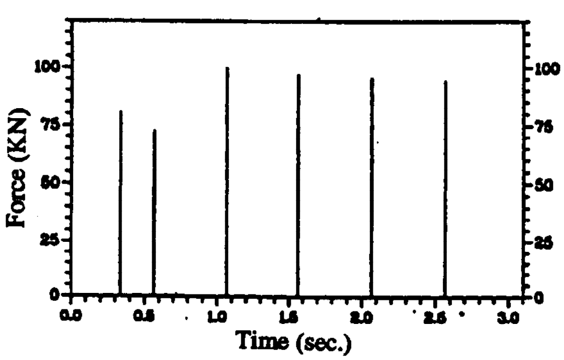


Fig. 12 : Impact force versus Time, for a SDOF, $K_c = 20$ K, $\xi = 5$ %, E = Xmax/2, f = 4 Hz.

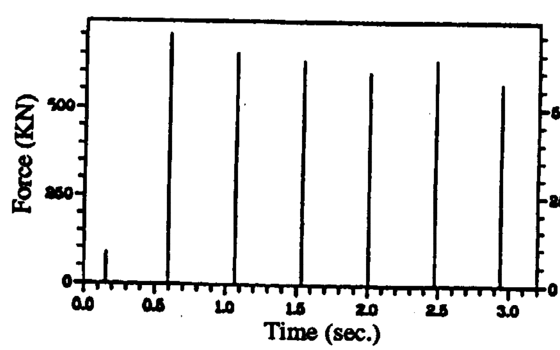


Fig. 13 : Impact force versus Time, of the 3 rd level, $K_c = 60$ K, $\xi = 5$ %, E = Xmax/2, f = 2 Hz.

Shock Period

We have been able to establish simple empirical relationships in calculating the shock periods $\overline{T}$, wathever system adopted. These are different for two types of system. We noticed that a nonlinear system vibration period depends on joint dimension, damping impact, and rigidity impact. The shock pulsation ϖ tends to approach 2ω more rapidly for a system of MDOF. When the impact rigidity is very great, the vibration period of shock T approaches T/2 wathever type of system.

SDOF :

For $C_C = 0 \;\; E = 0$ $\qquad$ $\overline{T} \cong \frac{T}{2}\left(1+\frac{1}{\sqrt{A}}\right)$ with $A = \frac{K_C + K}{K}$

For $C_C \neq 0 \;\; E = 0$ $\qquad$ $\overline{T} \cong \frac{T}{2}\left(1+\frac{1}{2\sqrt{A}}\right)$ with $A = \frac{K_C + K}{K}$

For $K_c = \infty$ $\qquad$ $\overline{T} = T/2$

MDOF

For $C_C = 0$ $\qquad$ $\overline{T} \cong \frac{T}{2}\left(1+\frac{1}{B}\right)$ with $B = 1 + \left(\frac{K_C + K}{2K}\right)^2$

For $C_C \neq 0$ $\qquad$ $\overline{T} \cong \frac{T}{2}\left(1+\frac{1}{B}\right)$ with $B = 1 + \left(\frac{K_C + K}{K}\right)^2$

For $K_c = \infty$ $\qquad$ $\overline{T} = T/2$

SHOCK BETWEEN STRUCTURES WITH DIFFERENT HEIGHTS

We considered collision of a six floor structure against an impact wall of smaller height. columns dimension equalled 0.25 x 0.25 x 3 m, floor masses equalled 26T, shocks were supposed to occur on the first four levels.

We noticed that besides local damage which can be caused to the structures, collision affects the response of the highest structure in a significant way. The ' whip cord ' effect which the upper part of the biggest structure undergoes, with PΔ effect can be catastrophic, see fig 14.

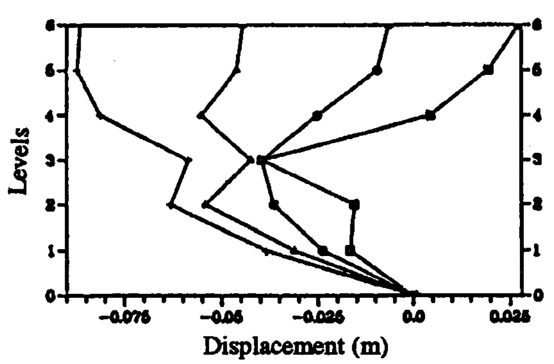
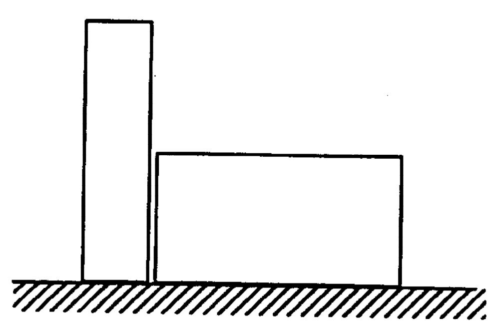


Fig. 14 : Displacement versus Time with shock, of a structure of 6 levels, f = 9.24 Hz.E = 0.015m.



Shock between structure with different heights.

FREQUENTIAL ANALYSES

This last study has enabled us to observe that for a SDOF system, in case of shock, several frequencies appear. Depending on the frequency excitation value, peaks appear for frequencies lower than the natural structural frequency or on both sides. A greater impact rigidity creates a peak shift towards higher frequencies with frequencies appearing, higher than the structural frequency itself, even in the case of fairly low excitation frequencies. For weak rigidity impact the high frequency is reduced.
For a system of MDOF the number of peaks is clearly greater than in the case of a SDOF system ; moreover their number increases with the excitation frequency. The increase in impact rigidity induces a peak shift towards the right ; certain peaks appear beyond the third mode frequency but with weaken amplitudes, see fig 15 and 16.

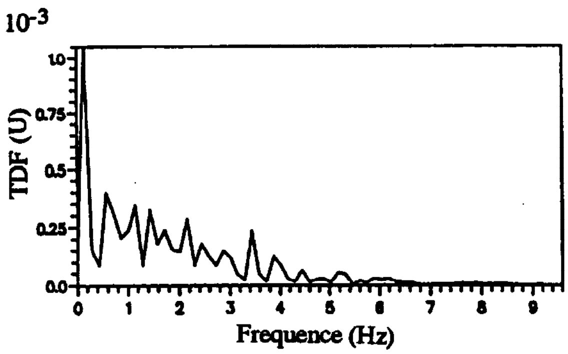


Fig. 15 : Frequential analysis of a structure of three level under shock. (TDF of the 2 nd level) K_c = 170 K, E = 0.02m, f = 3.95 Hz.

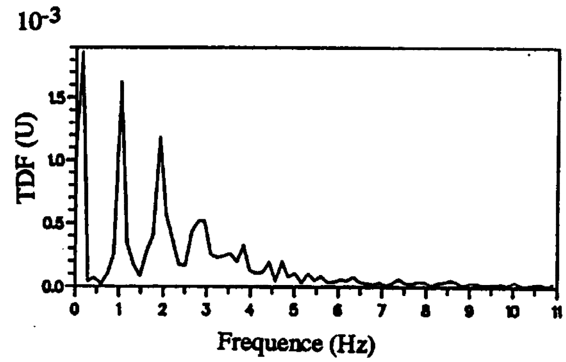


Fig. 16 : Frequential analysis of a structure of SDOF under shock K_c = 170 K, E = Xmax/2, f = 2.22 Hz.

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