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IMPACT PROBLEMS ON BASE-ISOLATED STRUCTURES

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ABSTRACT

One of the requirements of base isolated structures is the existence of a gap between the foundation and the surroundings, to allow the movement of the structure.

The aim of this study is the analysis of the possible collision of the isolated structure against the surrounding base.

The effect of the existence of bumpers to limit the base displacements and attenuate the structural response in the event of collision is also analyzed. Different types of bumpers are considered, from pure elastic devices to viscous devices, including combinations of elastic with viscous elements.

The study is based on the analysis of base isolated plane frame structures. For the assessment of the structural response with collision, the maximum base displacement, acceleration at the top and base shear were considered as the key controlling parameters.

The results show that it is not possible to eliminate, with the use of bumpers, the perturbation in the structural accelerations caused by collision. If high acceleration values are not a problem for the structure or what is inside it, then the use of bumpers can be a solution to minimize the gap dimension.

KEYWORDS

Base isolation; impact; collision, seismic gap.

INTRODUCTION

The concept of base isolation is an innovative and effective means of improving the seismic behavior of structural systems. One of the requirements of the base isolated structures is the existence of a seismic gap between the structure and the surroundings, to allow the free movement of the structure over the base isolation systems without any restriction.

In this study, however, the hypothesis of collision between the isolated structure and the surrounding space is admitted. This occurrence may take place if the structure experiments a base displacement larger than the expected, or when there is any deficient construction detailing of the gap.

The existence of bumpers to limit displacements and attenuate the structural response due to a collision is also analyzed. In the study, three types of shock absorbers are admitted: elastic, viscous or an association of elastic and viscous bumpers.

STUDY METHODOLOGY

The study was based on the analysis of the behavior of plane structures. The structural analysis was performed using the nonlinear program for dynamic analysis Drain-2D (Kanaan, 1975), modified to allow for the possibility of the collision of two elastic bodies (Mesquita, 1991), or the possibility of collision between a structure and an elastic or a viscous bumper.

The analyzed structure was a three span and three story plane frame with a non isolated natural frequency of 2.24 Hz. A bilinear isolation system was considered with a ratio between stiffness equal to 10, a yielding force level equivalent to 5% of the total structure weight and an isolated frequency of 0.5 Hz.

Artificial accelerograms with a peak ground acceleration of 0.3g and compatible with the response spectra presented in the Eurocode 8 (CEN, 1993) were used. In this study was considered a soil type C and a 20 seconds seismic action duration.

The first step was to evaluate the response of the isolated structure to the seismic action without the consideration of any perturbation of the free horizontal movement of the base. In this analysis a maximum base displacement of 0.285 m was obtained. Given this result, a 0.20m gap was admitted to allow the possibility of collision.

The second step was the analysis of the response of the isolated structure admitting the possibility of collision against a surrounding structure with very high stiffness. In figure 1 the evolution of the base displacement is represented, compared with the response without collision. In figure 2 the response in terms of acceleration at the top of the structure is presented.

It is important to observe, in figure 2, the perturbation on the acceleration at the top of the structure due to the impact. This perturbation is, however, attenuated along the response of the structure.

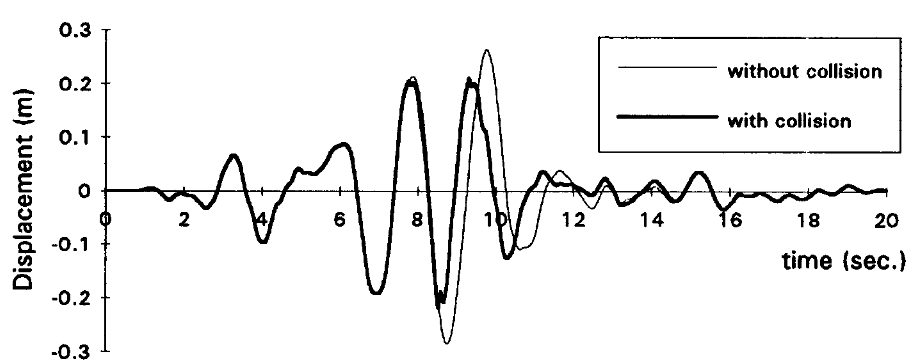

Figure 1 - Displacements at the base of the structure.

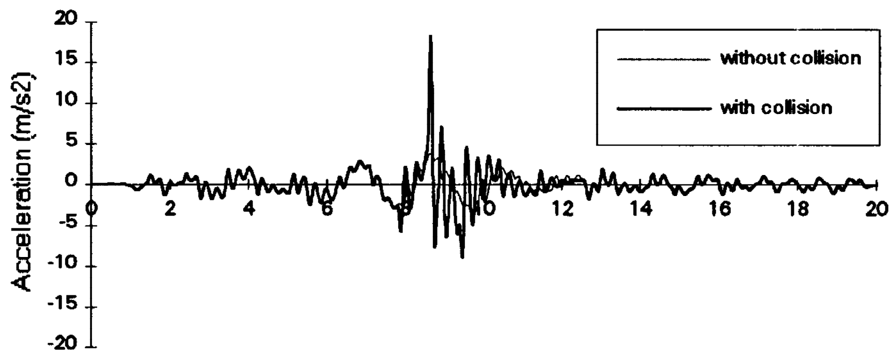

Figure 2 - Acceleration at the top of the structure.

To analyze the effect of the bumpers on the structural response with collision it was admitted that the gap between the bumper and the isolated structure was smaller that the total gap as represented in figure 3. The bumper gap is the distance between the isolated structure external surface and the surface of the bumpers or shock absorbers. In this study a total gap of 0.20m was admitted and four different values of the bumper gap were analyzed: 0.025m, 0.075m, 0.10m and 0.125m.

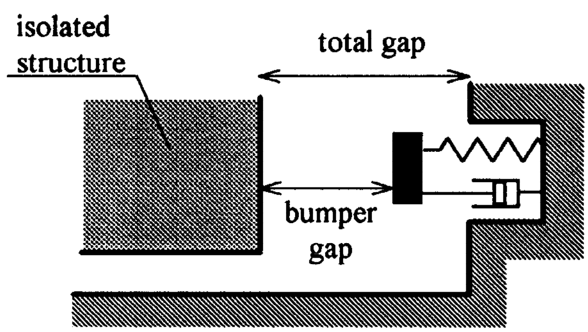

Figure 3 - Detail of the gap with bumper.

As already mentioned, three different kinds of bumpers were considered: elastic, pure viscous or a combination of these two. In figure 4 is represented a scheme to illustrate these situations and how the forces due the collision were evaluated. It is important to note that just compression forces were admitted in the contacting surface, because there is no connection between the structure and the bumper.

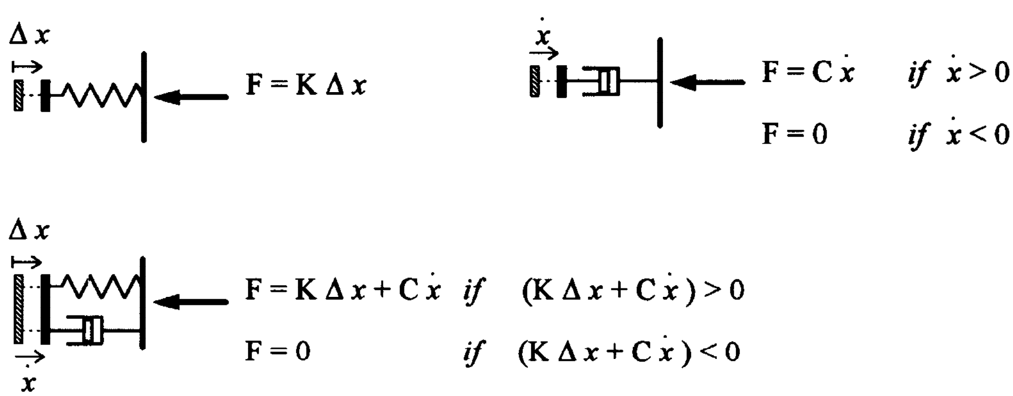

Figure 4 - Reaction forces on elastic bumpers, viscous bumpers and combination of both.

For the evaluation of the moment of impact, the relative displacement between the two points where the collision is admitted is tested. If a collision is detected, a reaction force is considered in the corresponding degree of freedom. The reaction force is calculated based on the formulation presented in figure 4. In this figure is presented the formulation adopted for the three considered types of bumpers. The reaction force is considered just on the time step after the impact. Then, a test for the collision is performed again and a new force considered, if necessary. The experience showed that, after the moment of collision, the structure and the bumper often move together for some time steps.

A parametric study was performed to evaluate the influence of the bumpers characteristics on the response of the structure. For the elastic bumpers, stiffness values ranging between 10^2 and 10^4 kN/m were analyzed, and for the bumpers with viscous behavior, values of C between 10^2 and 10^3 were considered. The K and C values considered for the viscoelastic bumpers were chosen after the analysis of the results obtained for the elastic and viscous bumpers, and the goal was to improve the structural behavior with a combination of elements of the two types.

RESULTS

The performance of the different shock absorbers systems was evaluated based on the maximum base displacement, the maximum acceleration at the top and the maximum shear force at the base of the isolated structure.

Whenever the maximum base displacement obtained for a certain solution of bumper was greater than the total available gap (0.20m in this study) that solution was rejected. Bumpers with characteristics that lead to shear forces greater than the forces obtained for the non-isolated structure were also rejected.

The results of the performed calculations are represented in the figures 5 to 7. In figures 6 an 7, the values obtained for the non isolated and for the isolated structure without collision are represented by two dotted lines.

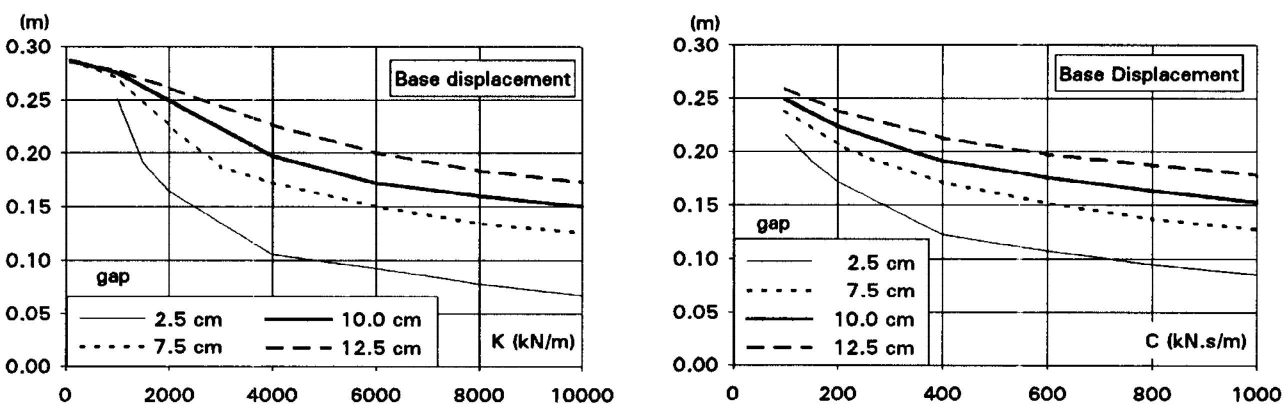

Figure 5 - Maximum base displacements for elastic and viscous bumpers.

Based on the results presented in figure 5, almost all the solutions considered in the analysis with a bumper gap of 0.125m were rejected. With this gap dimension, only for elastic shock absorbers with values of stiffness higher than 6000 kN/m or viscous elements with C values over 600 kN.s/m, the obtained maximum displacement is below 0.20 m. On the other hand, for the lower value of the gap dimension, values of K over 1500 kN/m or of C higher than 150 kN.s/m, are sufficient to guarantee displacements lower than the total gap.

The displacements represented in figure 5 are the total displacements of the structure, that means the sum of the value of the bumper gap with the bumper deformation. Comparing the results for the different gap values it is possible to conclude that the bumper deformation is almost the same.

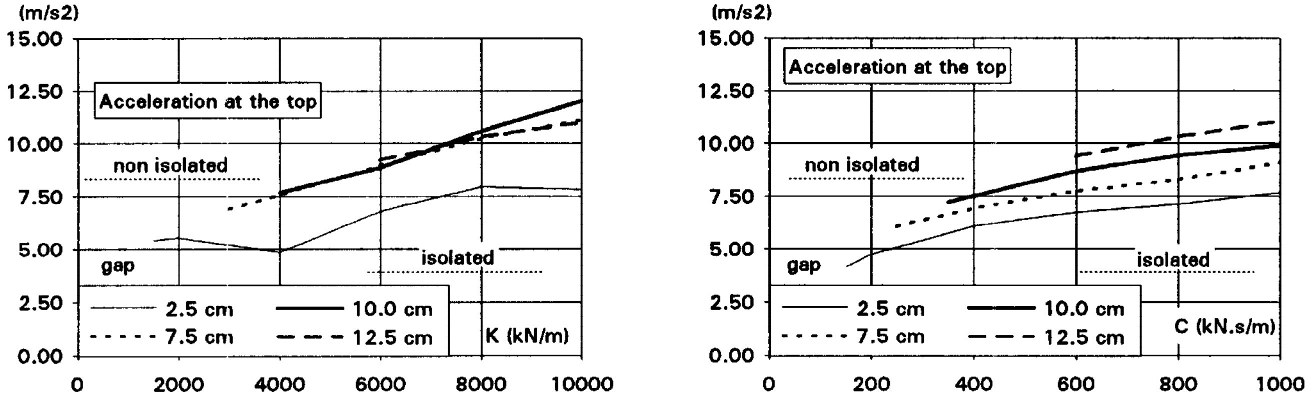

Figure 6 - Maximum acceleration at the top for elastic and viscous bumpers.

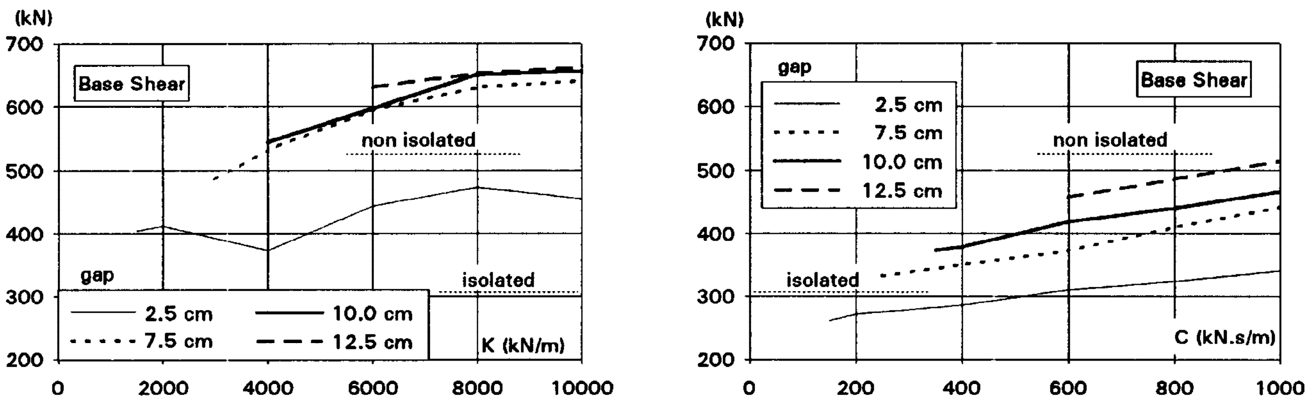

Figure 7 - Maximum shear forces at the base for elastic and viscous bumpers.

The results presented in figures 6 and 7 show that the viscous bumpers have a better behavior than the elastic ones. For similar values of maximum base displacement, the viscous bumpers present lower values of acceleration and shear at the base. Based on the shear force results, all the elastic bumpers tested for bumper gaps higher than 0.075m should be rejected. Even for the gap value of 0.075m only solutions with stiffness lower than 3000 kN/m are acceptable. Elastic bumpers are only acceptable for small values of the gap. For viscous bumpers, all the tested solutions were accepted, and there are some situations where the obtained shear forces are even lower than the shear forces on the isolated structure without collision.

From the results presented in figures 6 and 7 it can be concluded that the influence of the gap value is not important for the acceleration and base shear on the elastic bumpers, for gap values higher than 0.075m. On the other hand, viscous bumpers show lower values of acceleration and base shear for lower values of the gap.

The different cases of bumpers with elastic and viscous elements are listed in Table 1. The obtained results are also presented in that table. In the study of the viscoelastic shock absorbers, just the 0.075m bumper gap was considered.

As expected, it is possible to get better results with the association of elements of the two types. With this solution it is possible to choose more flexible solutions, deformation values in the limit of the total gap, with an important improvement in the values of top acceleration or base shear. For example, case 2 represents a solution with low values of stiffness K or damping C, and presents a maximum value of base shear near the value for the isolated structure without collision and with a maximum displacement of 0.16m.

The results obtained for the viscoelastic bumpers are similar to those obtained for the elastic or viscous elements alone, for the gap dimension of 0.025m, when comparing the maximum displacement or the shear at the base.

Table 1 - Results for the bumper with elastic and viscous elements (gap of 0.075m)

Case	C (kN.s/m)	K (kN/m)	Base Displacement (m)	Acceleration at the top (m/s^2)	Base Shear (kN)
1	200	2000	0.17	6.04	382
2	400	1000	0.16	6.69	366
3	600	4000	0.13	8.49	434
4	600	6000	0.12	8.92	464
5	800	4000	0.12	9.25	454

It is important to refer that the maximum values for base shear and top acceleration for the isolated structure without collision are, respectively, 304 kN and 3.80 m/s^2. That means that it is possible to get a bumper solution with an increase on the maximum shear base of about 20% (case 2 on table 1).

The analysis of the results in terms of acceleration shows that it is not possible to have a collision without having a significant increase in that parameter. Even for the solution with lower values of K or C, the maximum top acceleration is about 60% higher than in the situation without collision.

CONCLUSIONS.

The obtained results show that, if the dimension of the total gap is a restriction to the use of base isolation systems, the use of smaller gap associated with bumpers is a possible solution.

It is also shown that it is difficult to get a solution with displacements in the acceptable range of values and low values of acceleration or shear forces.

Collision causes great perturbation in the structural accelerations, which is not possible to eliminate with the use of dampers. Thus, if the structure or the equipment inside the structure is sensitive to high accelerations, the use of bumpers is not a good solution. In those cases a total gap should be carefully dimensioned.

If high acceleration values are not a problem for the structure or what is inside it, then the use of bumpers can be a solution to minimize the gap dimension. In this case, the gap can be designed for a seismic action with a lower return period, allowing the bumpers solution to work for the most severe earthquake.

The results show that the elastic bumpers are not an efficient solution, because they yield high acceleration values and shear forces at the base of the structure. Only with very low values of the bumper gap is possible to obtain values of shear forces lower than those obtained for the non isolated structure.

In general, the viscous elements yield better results, and in the some cases the results obtained for the collision with viscous bumpers are better than those for the structure without collision, but just for the maximum shear at the base.

In all cases, the behavior of the bumpers can be improved with the use of an association of elastic and viscous elements.

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