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SOME DIFFERENCES BETWEEN COUPLED WALL AND CANTILEVER WALL STRUCTURES

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SUMMARY

Coupled wall and cantilever wall structures are not only different in the design and shape. In order to reveal other differences, the base shear demand in coupled wall and cantilever wall structures were investigated in parametric studies by using nonlinear time history analyses. The parameters considered are the structure fundamental periods and damping models. The structures were designed by using New Zealand codes which incorporate seismic provisions. Two high-frequency earthquake records are used as the source of earthquake excitations. They are El Centro 1940 N-S (corrected) and Taft N69W. The results show that there are differences in the base shear forces between coupled wall and cantilever wall models regarding the above parameters. For the coupled wall model, a slight increase in the fundamental period decreases the base shear demand. On the other hand, for the cantilever wall model, a slight increase in the fundamental period increases the base shear demand. Moreover, the cantilever wall models are sensitive to the change of damping models, whereas the coupled wall models are not that sensitive. In addition, the change of damping coefficients in the cantilever wall model results in large difference in base shear forces, whereas in the coupled wall model, the change of damping coefficients results in small difference in base shear forces. Finally, the absence of rotation mass in the cantilever models results in much smaller base shear demand when a constant damping model was used whereas the phenomenon was not detected in the coupled wall models.

INTRODUCTION

Cantilever wall and coupled wall structures have long been recognised as efficient lateral-force-resisting systems. Both structures are categorised as structural walls. Structural walls provide a nearly optimum means of achieving the basic criteria that the designer will aim to satisfy in the seismic design, namely stiffness, strength, and ductility. Coupled wall structures are two or more cantilever wall structures which are coupled by coupling beams in each storey.

The base shear force prediction in the coupled wall and cantilever wall structures is important as the base of the structures undergoes substantial cyclic deformations in the inelastic range during large earthquake. Experimental investigations of reinforced concrete members under cyclic deformations in the inelastic range have shown that substantial strength degradations can be avoided only if the inelastic behaviour is controlled by flexure and not by shear. Thus for the seismic design of reinforced concrete structural members it is recommended that the shear capacity is not exceeded during an earthquake excitation [Paulay and Priestley, 1992].

First investigations of seismic shear forces have been performed in [Blakeley, Cooney, and Megget, 1975]. The model used was cantilever wall structure derived from an existing structure. They have led for a given yielding moment, the shear forces were higher than those which would correspond to the distribution of seismic loads in the elastic range, pointing to an increased importance of higher vibrational modes in case of inelastic behaviour. Magnification factors for shear forces based on [Blakeley, Cooney, and Megget, 1975] have been introduced in NZS 3101[SNZ, 1995]. Although the investigation was carried out on cantilever wall structures, it is implied in

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the standard that the recommendation can also be applied to coupled wall structures. However, it is pointed out by Paulay and Priestley [Paulay and Priestley, 1992] that the recommended values of shear-force magnification factors are based on a limited number of cases and could be modified as further studies become available.

According to Keintzel [Keintzel, 1990], it was found that for a number of storeys more than four, the magnification factor does not depend in fact on the number of storeys, but on the fundamental period. In his previous study [Keintzel, 1984], it was shown that the shear forces do not increase proportionally with the yielding moment of the shear walls. It was also shown in the same study [Keintzel, 1984] that the damping model had an influence on cantilever wall structures. Moreover, Aoyama [Aoyama, 1987] showed that the dynamic magnification of shear forces is larger for higher seismic input level. It means that the earthquake characteristic has influences on the base shear magnification of a structure.

In this paper, the authors want to show the results of a study on indicating differences between cantilever wall and coupled wall structures during earthquake attack. The study was focused on the influence of damping model and fundamental period alterations on the base shear forces of both structures. The study were started by designing coupled wall and cantilever wall structures by using New Zealand codes. Then, both structures were modelled and analysed in an inelastic dynamic analysis program called “Ruaumoko” [Carr, 1996]. Two common earthquakes were used as sources of excitations.

THE MODELS

The structure modelled is a symmetrical nine-storey building. Lateral forces are resisted in one direction either by coupled wall structures positioned at each end of the building or by cantilever wall structures positioned symmetrically within the building. There are two coupled wall or fourteen cantilever wall structures in the building. The amount of fourteen cantilever wall structures in one building is of theoretical interest rather than practical interest.

The coupled wall structures were derived from the design carried out by Pradono [Pradono, 1998]. The nine-storey structures were designed according to NZS 3101 [SNZ, 1995], NZS 4203 [SNZ, 1992], and as outlined by Paulay and Priestley [Paulay and Priestley, 1992]. The total weight of the building resisted by one coupled wall structure system is 29,520 kN. The fundamental period of the structure is 0.9 second. In this study, the structure was modelled by a beam-column element [Carr, 1996] for the wall; and a beam element [Carr, 1996] for the coupling beam. The design base shear at overstrength *Vop* was calculated as 3588 kN [Pradono, 1996]. The model is shown in Fig. 1(a). The beam-column elements were placed along the centrelines of the walls and the coupling beams with the beam elements being given rigid end blocks in order to model the coupling beams more appropriately.

The nine-storey cantilever wall structure was designed according to NZS 3101 [SNZ, 1995] and NZS 4203 [SNZ, 1992]. The total weight of the building resisted by one cantilever wall structure is 4217 kN. The fundamental period of the structure is 0.9 second. The influence of floor plate to the cantilever wall structures was assumed to be negligible. Therefore, the model is designed as single cantilever wall structure. The wall is modelled by a beam-column element [Carr, 1996]. The design base shear at overstrength *Vot* was calculated as 583 kN. The model is shown in Fig. 1(b). For the convenience of the comparison between the two model structures, the base shear forces of the cantilever wall model resulted from the inelastic time history analyses were multiplied by *Vop* / *Vot* , that is 3588/583.

THE PARAMETERS

The slight change of the fundamental period of the structure was done by altering the stiffness of the structure. Although in the NZS 3101 [SNZ, 1995] there has been a recommendation for an appropriate stiffness of a member, this parametric study was intended as a theoretical interest.

Two different damping models were incorporated in the models. The two models are the initial-stiffness Rayleigh damping (5% of critical damping in mode 1 and 10) and the constant 5% damping (5% of critical damping for all modes).

The other parameter is the rotation mass. Originally, this parameter was not expected to give large differences. However, as it gave interesting phenomenon, the parameter is then included.

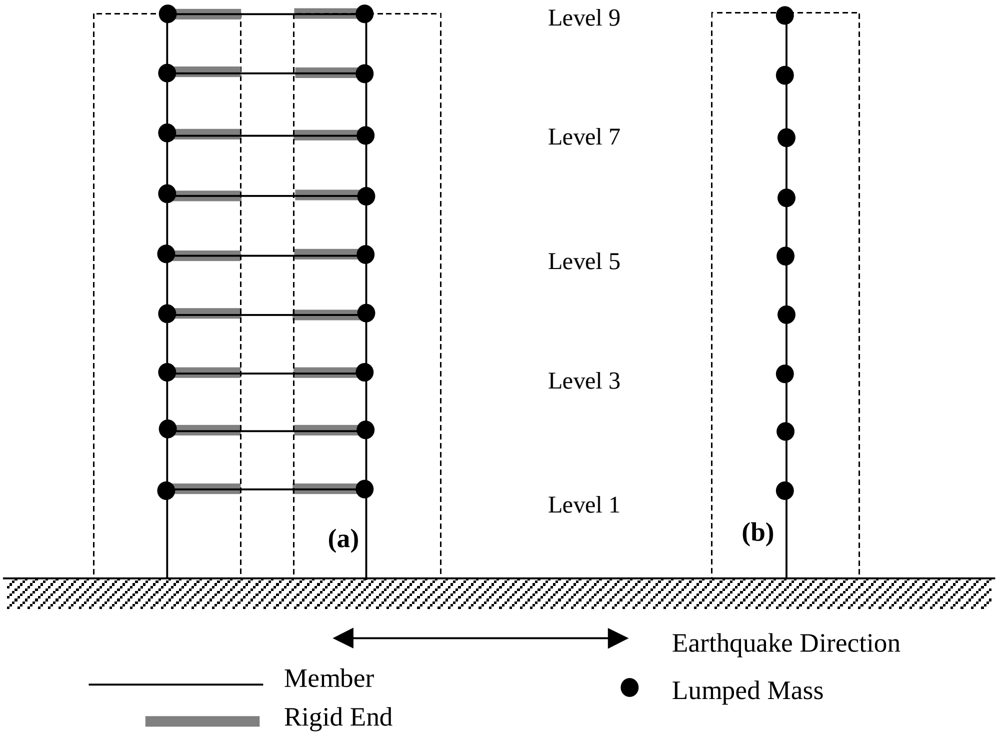


Fig. 1 The Model Analysed (a) Coupled wall Model (b) Cantilever wall Model

EARTHQUAKE RECORDS

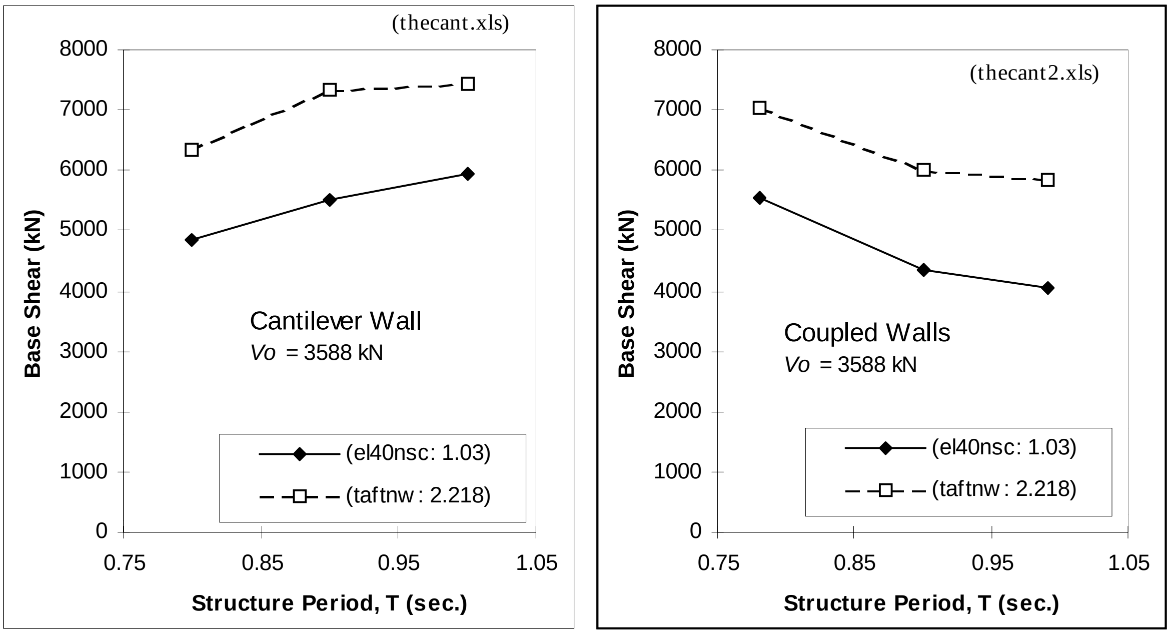
Two earthquake records were chosen. They were El Centro 1940 N-S (corrected) and Taft N69W. The earthquake records were chosen based on their characteristics and their popularity. The earthquakes were relatively low in magnitudes with predominantly high frequencies of the ground shaking. The same characteristic earthquake records have been used by Keintzel [Keintzel, 1984, 1990], therefore the result is hoped to be comparable. The earthquake records were then scaled by using their response spectra so that they match the design base-shear coefficient in NZS 4203 [SNZ, 1992] for intermediate soil sites.

The calculated scale factor for the El Centro 1940 N-S (corrected) is 1.026, whereas for the Taft N69W is 2.218. Both earthquakes were then coded as "el40nsc:1.03" and "taftnw:2.218" for the scaled El Centro 1940 N-S (corrected) and the scaled Taft N69W earthquakes, respectively.

RESULTS OF INVESTIGATIONS

The inelastic analyses were carried out using a computer program called "Ruaumoko" [Carr, 1996]. The maximum values of the total base shear were determined from these analyses.

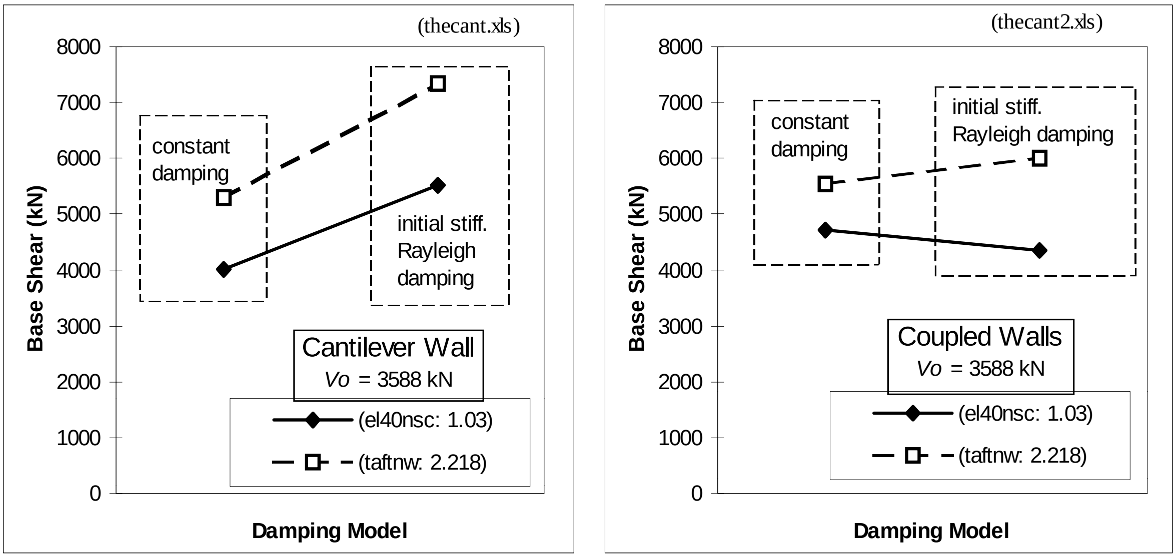
The first results are related to the slight change of the structure’s period. It is shown in Fig. 2(a) that for the cantilever wall model, an increase in the fundamental period of the structure increases the base shear demand. This result is in agreement with the result from Keintzel [Keintzel, 1990]. On the other hand, for the coupled wall model, an increase in the fundamental period decreases the base shear demand (Fig. 2(b)). The decreasing phenomenon is in agreement with the results from Keintzel [Keintzel, 1990] but for the elastic-system cantilever wall model with the ratio of flexural to shear stiffness of 0.25.



(a) (b)

Fig. 2 Base Shear Demand of Wall Models as a Function of Structure's Period With Initial Stiffness Rayleigh Damping (a) Cantilever wall (b) Coupled Wall

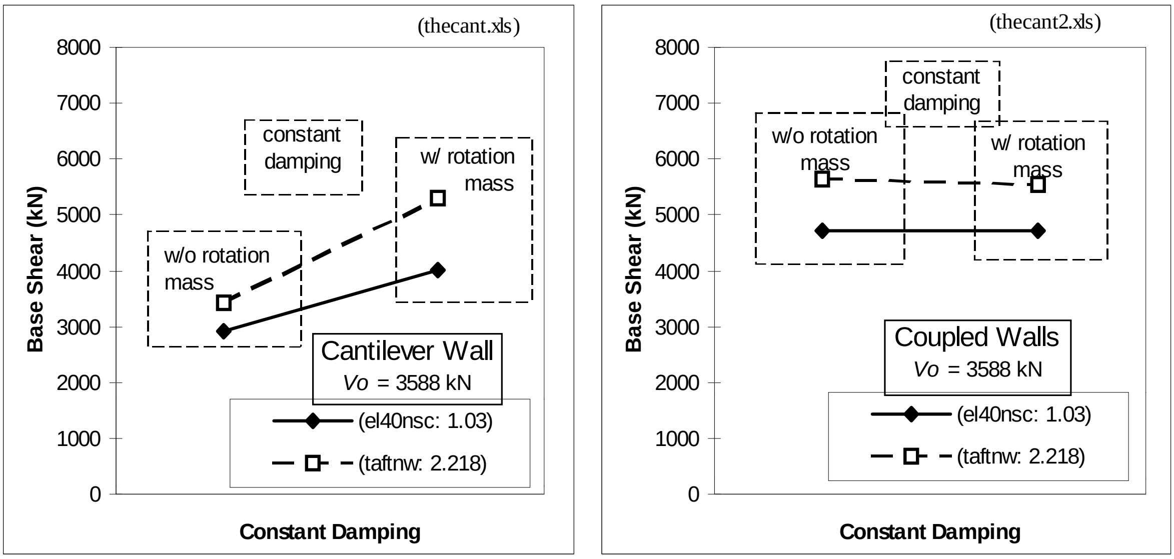
The other parametric study was carried out on the damping model. It is shown in Fig. 3(a) that for the cantilever wall model, the constant damping model results in relatively smaller shear forces than the initial stiffness Rayleigh damping model. On the other hand, the phenomenon is unlikely true for the coupled wall model (Fig. 3(b))



(a) (b)

Fig. 3 Base Shear Demand of Wall Model as a Function of Damping Model (a) Cantilever wall (b) Coupled wall

The difference is more obvious when the rotation mass of each node is removed from both models. The rotation mass is small compare to the x-direction mass. The effect of omitting the rotation mass is expected to be negligible. However, this is not true for the cantilever wall model. As it is shown in Fig. 4(a), the cantilever wall model with constant damping but without rotation mass results in much smaller base shear force. On the other hand, for the coupled wall model, the phenomenon is not detected (Fig. 4(b)).



(a) (b)

Fig. 4 Base Shear Demand of Cantilever Wall Model with and without Rotation Mass for Constant Damping
(a) Cantilever wall (b) Coupled wall

The observation of the damping force in cantilever wall model shows that the damping moment in each node is zero. This phenomenon was only found in the constant damping model without rotation mass. For the initial stiffness Rayleigh damping, the removal of the rotation mass did not alter the damping moment. Moreover, the removal of rotation mass in the cantilever wall model results in unreasonably small roof displacement. The displacement is only in the order of 0.001 m. It is therefore important in constant damping model to specify all the dynamic degree of freedom in every node, especially for cantilever wall structures.

DISCUSSION

The decreasing base shear force in coupled wall model as the fundamental period slightly increases is in agreement with the result from Keintzel [Keintzel, 1990] for the elastic system cantilever wall model with the ratio of flexural to shear stiffness of 0.25. This phenomenon can be attributed to the fact that the wall's ductility demand in coupled wall structures is much smaller than that in cantilever wall structures. An illustration of this phenomenon is shown in Fig. 5. It shows that the walls in coupled wall structures go elastically more often than the walls in cantilever wall structures.

The choice of damping models is not critical in coupled wall structures as the structures are stiff. According to the work carried out by Chrisp [Chrisp, 1980], the choice of the damping models can be critical if the structure has a member which goes inelastic without any resistance from other members. The damping force in this member can be relatively large and affects the overall response. In fact, for coupled wall structures, when a coupling beam goes inelastic, wall members can resist further rotation of the coupling beam and when the tension wall goes inelastic, the compression wall still can resist further movement of the tension wall. This stiff structure result in small damping forces and therefore small damping influences to the overall response.

On the other hand, for cantilever wall structures, when the wall goes inelastic, there is no other member that can resist further movement of the wall. The movement will be mostly resisted by damping forces. This situation produces large damping forces which influence the overall response. This is shown in Fig. 6 that the damping force in the cantilever wall model is larger than that in the coupled wall model.

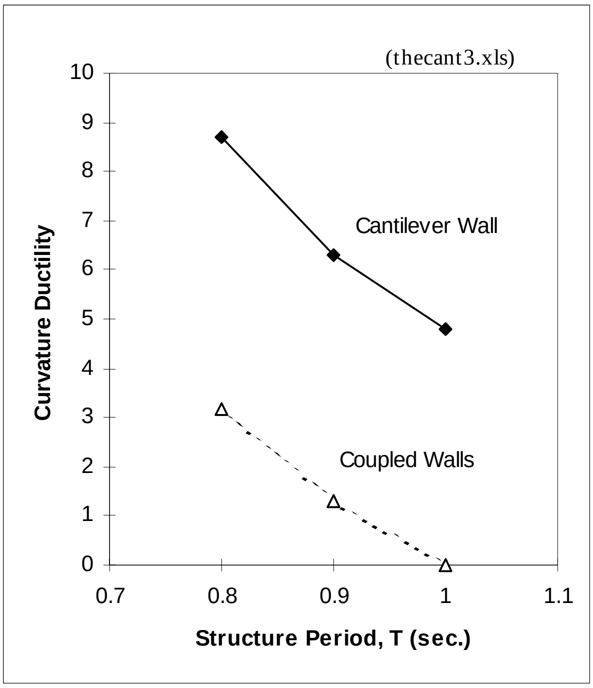


Fig. 5 Ductility Demand in Coupled Wall and Cantilever Wall Models (Earthquake: el40nsc: 1.03)

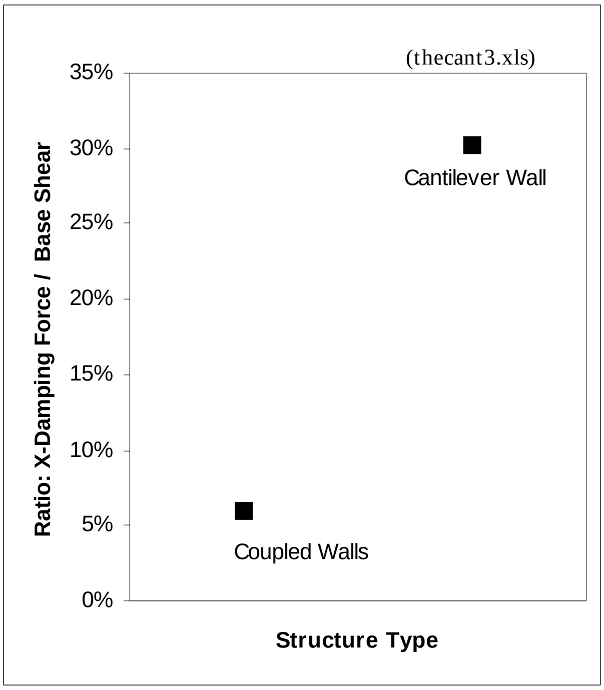


Fig. 6 X-Damping Force Ratios in Coupled Wall and Cantilever Wall Models (5% Constant Damping)

The large damping force in the cantilever wall structure is attributed mainly to the use of the viscous damping. The use of viscous damping is primarily a matter of mathematical convenience rather than structural accuracy. Viscous damping is applicable to displacement of oil in ideal dashpots. It is rather difficult to accept that it is equally applicable to concrete or masonry structural elements. In fact, the predicted influence of viscous damping on a linear elastic system appears to produce behaviour opposite to that observed in reinforced concrete and masonry structural elements [Paulay and Priestley, 1992]. Thus, viscous damping does not represent actual behaviour, although the errors are typically not large at the levels of damping (2 to 7%) normally assumed for elastic response of structural concrete. Paulay and Priestley [Paulay and Priestley, 1992] recommend that it is probable that more realistic representation can be achieved by ignoring damping and treating the stiffness as a function of displacement, effective strain rate, and direction.

The above recommendation from Paulay and Priestley was analytically tested by altering the percentage of critical damping in both type of structures. It was found that for coupled wall structures, the effect of altering the percentage of critical damping is small. On the other hand, for cantilever wall structures, the effect of altering the percentage of critical damping from 0.1% to 5% is large. It is calculated from Fig. 7 that the use of 0.1% (instead of 5%) of critical damping in cantilever wall model increases the base shear force by 67%, whereas for the coupled wall model the increase is only 9%.

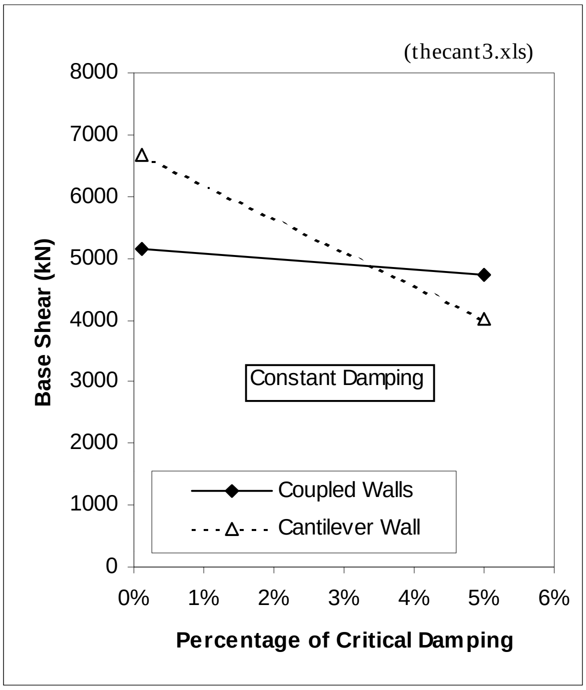


Fig. 7 The Effect of Altering the Percentage of Critical Damping in Coupled Walls and Cantilever Wall Models (Earthquake: el40nsc: 1.03)

CONCLUSION

The parametric studies show that there are differences in base shear forces between cantilever wall and coupled wall structures. The differences here are regarding to the change of the fundamental period and the use of different damping models in the structures. The increase of fundamental period in the cantilever wall model increases the base shear force. On the other hand, the opposite effect was found in the coupled wall model. Moreover, for cantilever wall model, the constant damping force results in relatively smaller base shear forces than the initial-stiffness Rayleigh damping model. In contrary, the phenomenon is unlikely true for the coupled wall model

When the constant damping model was used, the removal of rotation mass in cantilever wall structure has a large effect in the base shear force, whereas the effect is small for the coupled wall structure. Therefore, for cantilever wall structures it is important to specify all the dynamic degree of freedom if the constant damping model is used. Finally, for coupled wall structures, the effect of altering the percentage of critical damping is small. On the other hand, the effect is large for cantilever wall structures.

The effect of different damping models on the response of cantilever wall structures needs further investigations.

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