CYCLIC LOADING TEST OF SMALL SCALE BRIDGE PIER MODELS WITHOUT SEISMIC DETAILING

Ick-Hyun KIM[1], Hyun-Woo LIM[2], Gui-Hyun JUHN[3] And Jae Kwan KIM[4]

SUMMARY

A cyclic loading test was done for the reinforced concrete bridge column with hollow rectangular cross section. The test specimen is a 1/5-scale model of the prototype. It is designed for the loading conditions other than seismic load without seismic detailing. The column showed premature bond failure of vertical longitudinal reinforcing bars near the interface between column and the foundation. The seismic capacity of the bridge pier is found to be insufficient. For the seismic upgrading of the bridge supported by the prototype columns, shear keys are installed at the top of each pier while shear key stopper are installed on the deck. The capacity of a shear key stopper is investigated by static loading test. Seismic capacity spectrum method is employed to evaluate the capacity of the bridge with shear keys. A simple evaluation procedure is proposed for the seismic upgrading design of bridges with shear keys.

INTRODUCTION

In 1992, seismic design requirements were included into the design specifications of highway bridges in Korea. The adopted seismic design approach is based on those of AASHTO Specifications. Since the majority of existing bridges do not have seismic detailing, seismic upgrading may be necessary for critical bridges. Many structures without seismic detailing are known to have inherent lateral load carrying capacity [Lee *et al.*, 1998, NCEER, 1996a, NCEER, 1996b]. The ductility demand in low and moderate seismicity regions may not be as high as that in high seismicity regions. Therefore the first step toward the rational seismic upgrading of existing bridges is accurate evaluation of the inherent strength of existing bridges without seismic detailing. Based on the data, seismic upgrading method of bridges has to be determined.

Reinforced concrete columns of solid circular section and hollow rectangular section are two substructure types most widely used for bridge piers in Korea. The seismic behavior of RC column with hollow rectangular section has not been well understood yet compared to those with circular sections. Before introducing the seismic design into the bridge design specifications, there was no specific requirement on the confinement steel and cut-off or splice of longitudinal reinforcing bar. In an extreme case all the longitudinal bars were cut off at the same height and extended with lap splices. Another difficulty of seismic upgrading of existing bridges is lack of accurate as-built data on the construction details. Therefore the seismic behavior and capacity of the pier model with the particular details must be investigated through tests of column models. In the design without due consideration to the seismic load, many bridges are of multi-span continuous type with the deck fixed at a single pier in longitudinal direction. Hence they are very vulnerable to the lateral load acting in longitudinal direction.

There are many methods in use for the seismic upgrading of bridge piers. One popular method is jacketing the column with steel plate or with composite materials. But in moderate seismicity region such method may not be adequate especially for those with very poor seismic reinforcement details. Especially for multi-span continuous bridges the lateral load need to be distributed to several piers. One practical approach is installing shear keys that

[1] *Researcher, Korea Earthquake Engineering Research Center, Seoul, Korea*
[2] *Graduate Student, Department of Civil Engineering, Seoul National University, Seoul, Korea*
[3] *Manager, Korea Infrastructure Safety & Technology Corporation, Seoul, Korea*
[4] *Associate Professor, Department of Civil Engineering, Seoul National University,Kwanak-Ku,Seoul, Korea*

can transmit longitudinal lateral load to the piers other than fixed one. Shear keys are adopted in the bridge design and shear key stoppers are installed at the bridge decks. In Korea shear key stoppers are designed to have adequate shear strength to resist the shear force. But its actual behavior need be verified through tests. If they can be implemented properly, shear keys with stoppers can be a simple and low cost solution for the seismic upgrading of existing bridges in moderate seismicity regions. But one obstacle to the implementation is lack of simple procedure for the seismic evaluation of the bridges with shear keys.

This paper reports two different test results. One is the cyclic loading test of 1/5 scale model of bridge pier with hollow rectangular section. The other is static loading test of a reinforced concrete block with shear key stopper. Seismic capacity curve of bridge pier model is derived based on the column test results. Simple evaluation procedure is developed for the seismic upgrading of multi-span continuous bridges with shear keys.

CYCLIC LOADING TEST OF RC COLUMN WITH HOLLOW RECTANGULAR SECTION

The prototype of a column with hollow rectangular section is selected from the design of a existing bridge. Its height is 25m and its cross section dimension is 5.2m×3.0m. The wall thickness is 0.5m. The tie bars do not have hooks. The 1/5 scale model is designed as shown in Figure1. Details between the prototype and scale model are compared in Table 1. Concrete strength is assumed to be the same. But smaller aggregate size is specified for the model. The diameter of the longitudinal bars is selected to keep the reinforcement ratio almost identical. The thickness of cover concrete is estimated based on the conical failure mode of the concrete surrounding longitudinal bars [Priestley *et al.*, 1996]. Round bars are used for the lateral reinforcement instead of deformed bars because of the difficulty in procurement. The plastic hinge length is estimated using the formula proposed by Priestly [Priestley *et al.*, 1996]. The test set-up is as shown in Figure 3. The loading history is provided in Figure 4. The number of cycles at each load step is determined to be 2 after personal discussion with Professor Maekawa of University of Tokyo. The magnitude of design earthquakes in moderate seismicity regions is considered to be smaller than in the active tectonic regions. Another factor is that the damage will be limited to the epicentral region. Therefore columns are expected to experience less number of load reversals in low and moderate seismicity regions. The yield displacement is defined as the displacement at 0.75 P_M divided by 0.75 [William and Geraldine, 1989].

The load-displacement history is given in Figure 5. As can be seen, the maximum load does not reach P_M. It is because of the premature bond failure at the splices of longitudinal bars. The crack pattern developed at the load step 0.75 Δ_y is given in Figure 6. The pullout of steel bars can be recognized in Figure 7. From these results the ductility of the prototype is determined to be 1.5 and the maximum strength is 0.83 P_M as depicted in Figure 5. Accidentally it was found later that the concrete strength of test specimen was much lower than the specified one because of mistakes of the supplier.

STATIC LOADING TEST OF SHEAR KEY STOPPER BLOCK

A static loading test has been conducted for the 1/4 portion of shear key stopper shown in Figure 9. This stopper is attached to the deck through embedded stud bolts. The test set-up is depicted in Figure 10. Details of the design properties are provided in Table 2. Even though the stud bolts of shear key stopper is designed to have sufficient shear strength, the failure mode observed in the test was different from the design assumption. As can be identified in the Figure 11 the shear key stopper lost its capacity because of the pullout of stud bolts. Figure 12 shows load-displacement curves of the test specimen. The loss of capacity is very abrupt without ductile behavior. It indicates that in the design of shear key stoppers, the pullout failure mode of stud bolts should be prevented and appropriate safety factor need be introduced.

SEISMIC UPGRADING WITH SHEAR KEYS

A simple evaluation procedure for seismic upgrading of existing multi-span continuous bridges is developed. A similar idea is explained for the design in transverse direction in the reference [Priestly *et al.*, 1996]. The superstructure is considered fixed at a single pier to prevent movement in longitudinal direction. The lateral load carrying capacity is assumed to be identical for all the bridge piers. If the super structure can be considered to be a rigid body for the horizontal movement it can be modeled as a SDOF system. The maximum gap is assumed to be constant at each shear key. But the relative location will be randomly distributed. For example (M–1) shear keys are assumed used to upgrade the seismic capacity. One extreme case is that all the shear keys are in contact with the stopper at the same side at the onset of the seismic action. Then the capacity will be M times of single column capacity. Another extreme case will be all the shear keys are in contact with the shear key stoppers at the other side. Then the fixed column has to resist the entire horizontal load until other piers start to share the load. The design requirement will be that the maximum displacement does not exceed the ductility capacity of the fixed column. The capacity curve can be converted into a ADRS capacity spectrum and compared with the demand spectrum in the same plot. Then it can be easily find out whether it meets the desired performance as shown in Figure 13.

CONCLUSION

A cyclic loading test of the reinforced concrete bridge column with hollow rectangular cross section demonstrated that it does not have inherent lateral load carrying capacity without seismic detailing. The model lost its strength due to the bond failure of longitudinal bars. The steel jacketing may not be a good solution for the hollow rectangular section because of uncertainty in confinement effect. Shear keys may be a good alternative retrofit method. A shear key stopper block model was subjected to the static test. Contrary to the design assumption it lost its capacity due to the pullout of the stud bolts in very brittle pattern. If an appropriate safety factor were introduced for the shear key stoppers, shear keys can be a good retrofit method for multi-span continuous bridge. A simple evaluation procedure is proposed for the seismic upgrading of multi-span continuous bridges with shear keys. The procedure can be cast in the form of capacity spectrum method [ATC, 1996]. The procedure appears to be very simple to apply.

ACKNOWLEDGEMENT

This work was supported partly by the Korea Science and Engineering Foundation (KOSEF) through the Korea Earthquake Engineering Research Center at Seoul National University and partly by the Korea Infrastructure Safety & Technology Corporation. The authors wish to express their appreciation for the valuable advice by Professor K. Maekawa of the University of Tokyo.

REFERENCES

ATC (1996), *Seismic Evaluation and Retrofit of Concrete Buildings*, Volume 1, Report SSC 96-01, ATC-40, Applied Technology Council, Redwood City, California.

Lee, H.-S., Woo, S.-W., Heo, Y.-S. (1998), "Inelastic behaviors of a 3-story reinforced concrete frame with nonseismic details", *Proc., of KCI Conference-Spring 1998*, 10, 1, pp429-432.

NCEER (1996a), *Seismic Evaluation of a 30-Year Old Non-Ductile Highway Bridge Pier and Its Retrofit*, Technical Report NCEER-96-0008, National Center for Earthquake Engineering Research, Buffalo, New York.

NCEER (1996b), *Seismic Performance of a Model Reinforced Concrete Bridge Pier Before and After Retrofit*, Technical Report NCEER-96-0009, National Center for Earthquake Engineering Research, Buffalo, New York.

Priestley, M.J.N, Seible, F and Calvi, G.M.(1996), *Seismic Design and Retrofit of Bridges*, John Wiley & Sons, Inc. New York.

William C. Stone and Geraldine S. Cheok(1989), *Inelastic Behavior of Full-Scale Bridge Columns Subjected to Cyclic Loading*, NIST Building Science Series 166, National Institute of Standards and Technology, Gaithersburg.

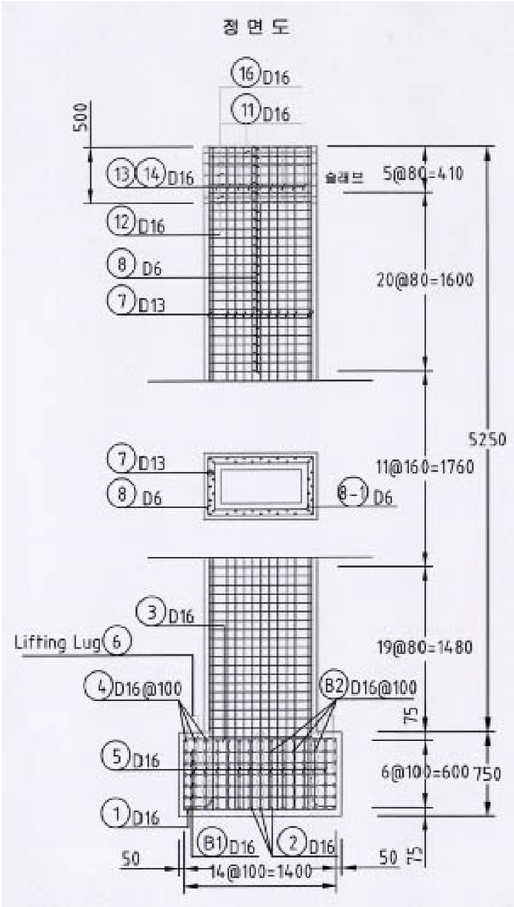


Figure1a : 1/5 scale model of pier

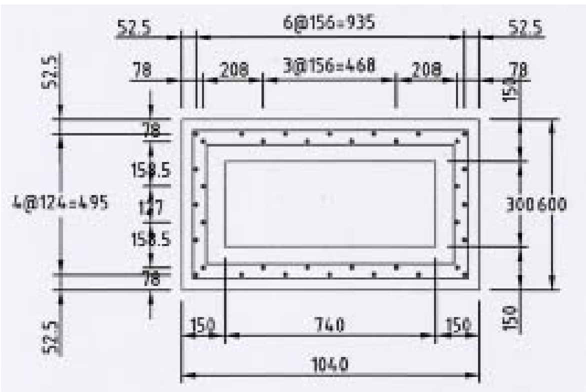


Figure 1b : Details re-bar arrangement

Figure 2 : Cut-off of longitudinal bars

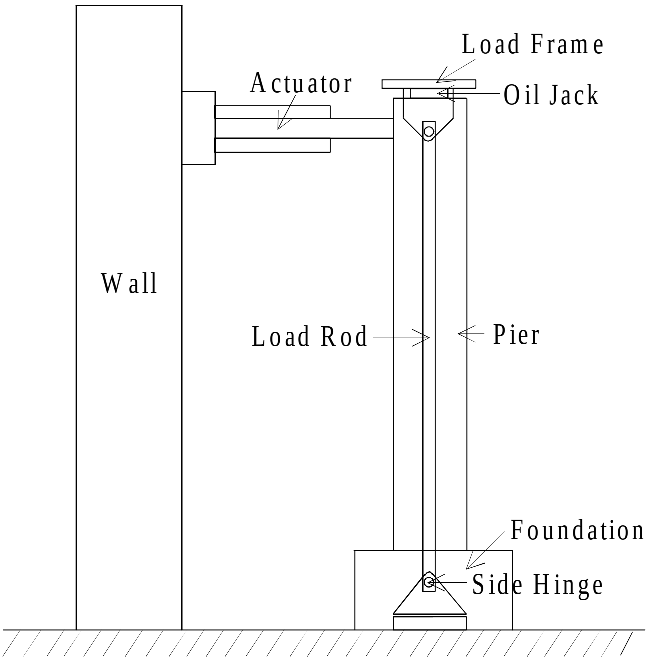


Figure 3 : Set-up for the cyclic loading test

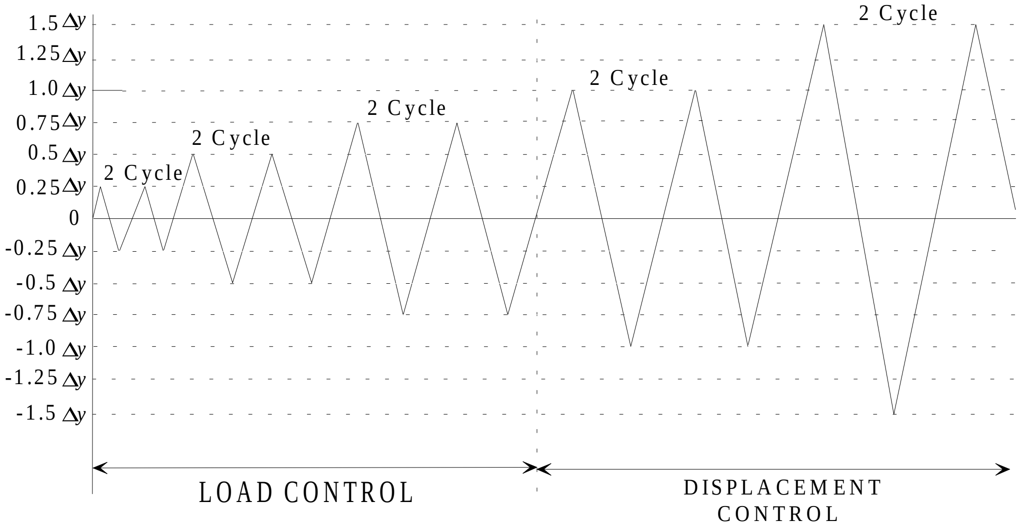


Figure 4 : Loading history

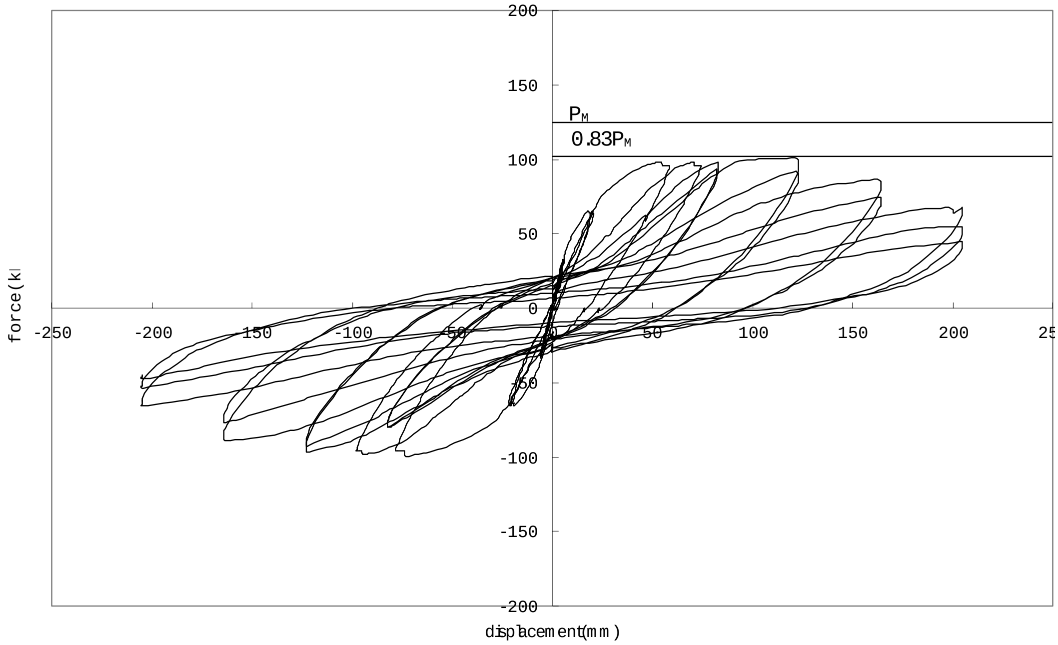


Figure 5 : Load-displacement response

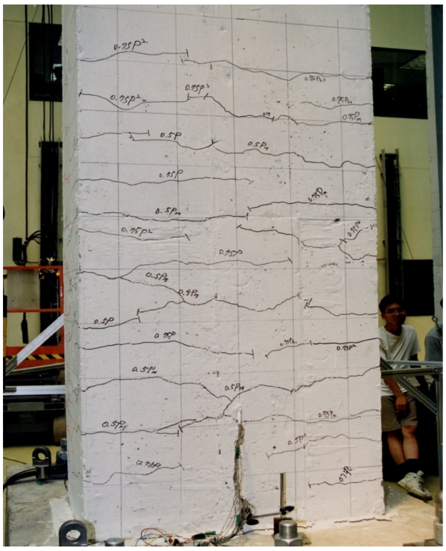
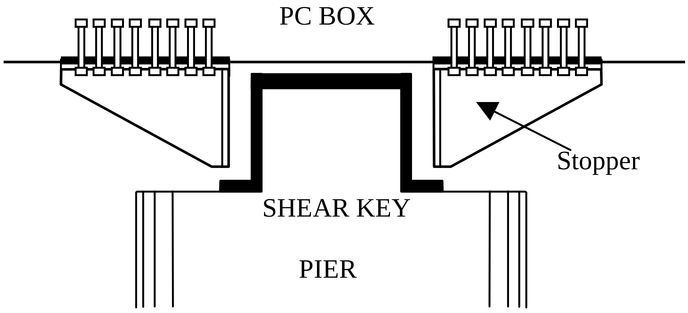


Figure 6 : Crack pattern in the loading step 0.75.

Figure 7 : Failure of scale model



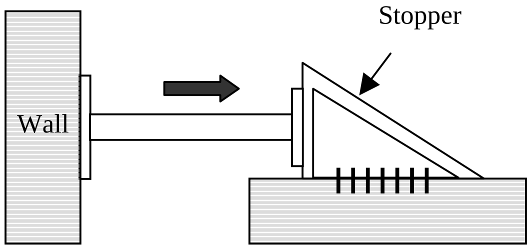


Figure 8 : Shear key and stoppers

Figure 10 : Test set-up of shear key stopper

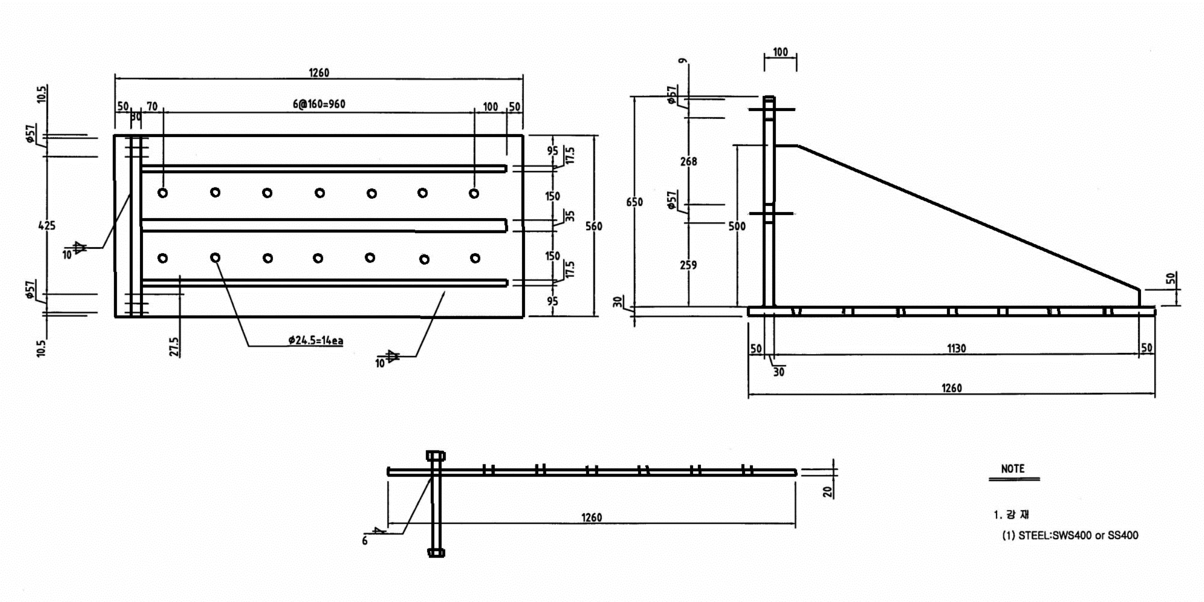


Figure 9 : Details of shear key stopper

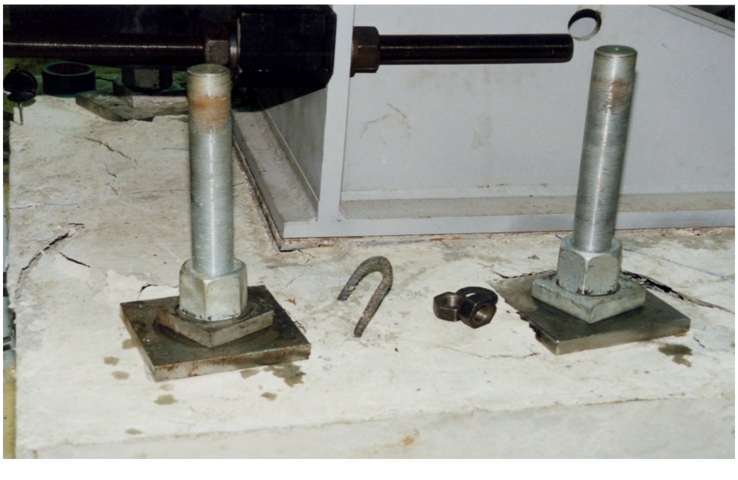


Figure 11 : Anchorage failure of shear key stopper

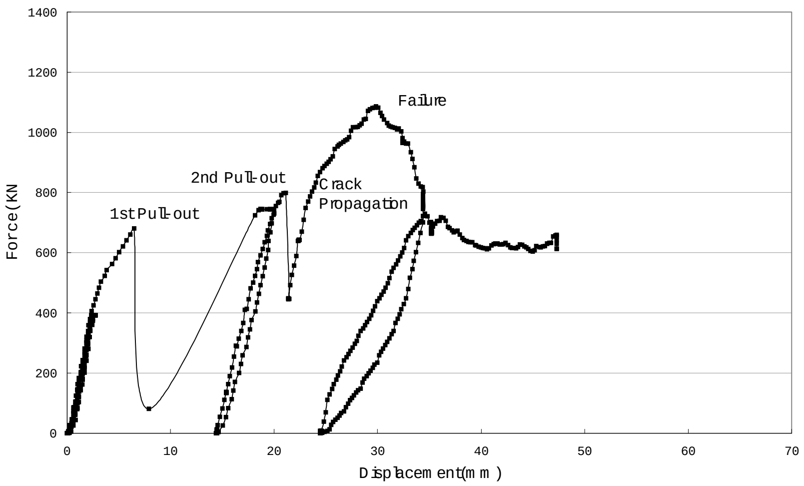


Figure 12 : Load-displacement response of shear key stopper

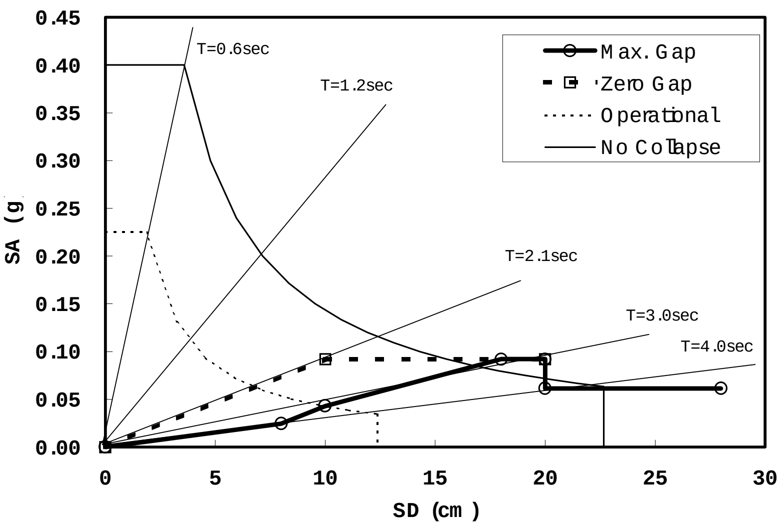


Figure 13 : Example of ADRS capacity spectrum for a bridge with two shear keys