# A STUDY ON THE IMPROVEMENT OF SEISMIC PERFORMANCE OF THE EXISTING ARCH BRIDGE USING THE BACKUP BEARING

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## ABSTRACT

The 1995 Hyogoken-nanbu earthquake showed that steel bearings are vulnerable members in the bridge system to strong earthquake ground motion. The restrainer and the pedestal support with the sliding plate are proposed to be installed as the backup bearing for the improvement of seismic performance of the existing arch bridge. The effect of the restrainer gap on the peak response of the bridge is studied. The seismic response analysis considering the existing bearing failure is conducted. The study shows that the restrainer gap enables the peak response displacement to decrease because of the bearing fuse effect that is the seismic isolation effect after the bearing failure.

## 1. INTRODUCTION

Many bridge structures suffered heavy damage from the Hyogoken-nanbu earthquake that struck the vicinity of Kobe city in Japan on Jan. 17, 1995. The seismic retrofit program for the existing bridge structures made a full-fledged start slightly behind the restoration of the damaged structures in Hanshin Expressway Public Corporation. Until today, most of the middle- or small-scale bride structures have already strengthened seismically against the equal intensity of the Hyogoken-nanbu earthquake ground motion. But the long-span bridges mainly located in Bay Route of the Hanshin Expressway network have not retrofitted yet due to the technical and financial problems.

The restrainer and the pedestal support with the sliding plate are proposed to be installed as the backup bearing for the improvement of seismic performance of the existing arch bridge. The effect of the restrainer gap to the bridge response is studied. The restrainer is the device to prevent excessive relative displacements between the superstructure and the bridge column when the bearing fails. The Hyogoken-nanbu earthquake proved that existing steel bearings are vulnerable structural members in the whole bridge system and have a fair chance of suffering some damage from strong earthquake ground motion. Since the bearings of the long-span bridge are very difficult to exchange, the restrainer should be installed to prevent excessive relative displacement between the superstructure and the bridge support in case of malfunction of the bearings. The effects of the restrainer gap to the bridge response are focused in this study. The seismic safety of the arch bridge is taken into consideration in terms of the peak response displacement.

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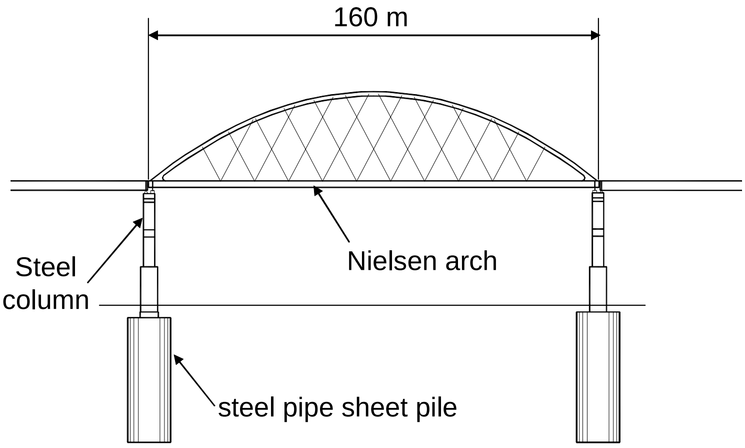



Figure 1 Nielsen steel arch bridge

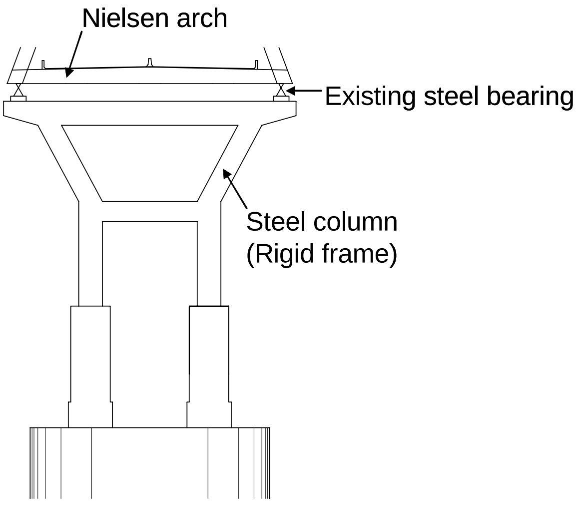
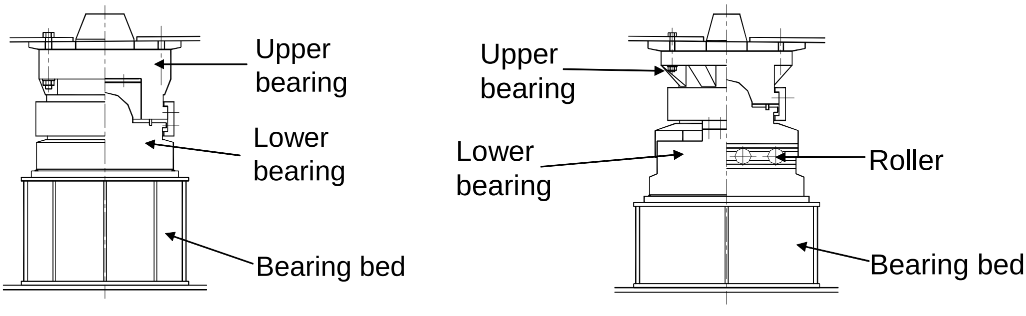
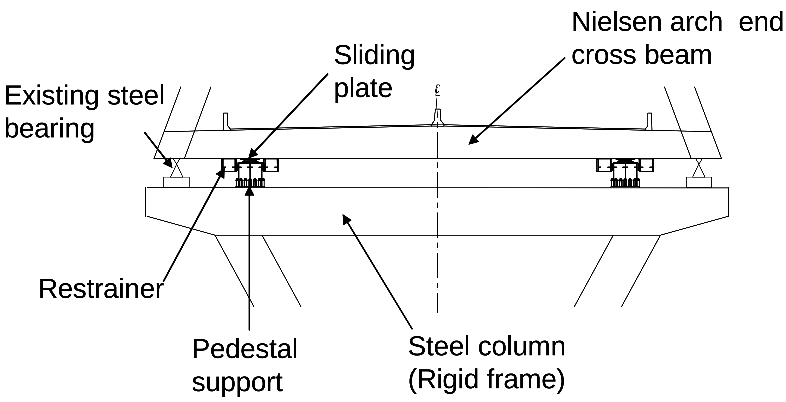



Figure 2 Steel column

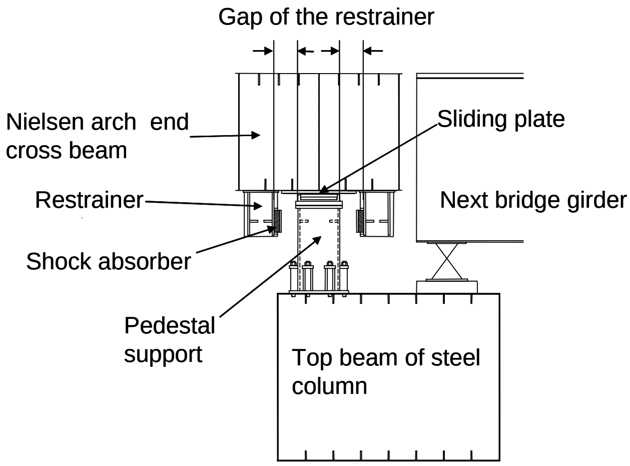



(a) Fixed condition (b) Movable condition

Figure 3 Steel bearing




(a) Transverse direction




(b) Longitudinal direction

Figure 4 Backup bearings

## 2. THE EXISTING ARCH BRIDGE AND THE BACKUP BEARING

Figure 1 shows the Nielsen steel arch bridge located in Bay Route of the Hanshin Expressway network. The span length is 160 m. The foundations are the steel pipe sheet piles. The bridge supports are the steel rigid frame column, shown in Figure 2. The arch girder is simple-supported. The fixed bearing is the pivot bearing, shown in Figure 3(a). The movable bearing is the pivot roller bearing, shown in Figure 3(b).

The backup bearings are shown in Figure 4. They consist of the restrainers and the pedestal supports. The restrainer limits the excessive relative displacement between the superstructure and the bridge supports to prevent the girder from falling. The pedestal supports take over vertical support after the existing bearing failure.

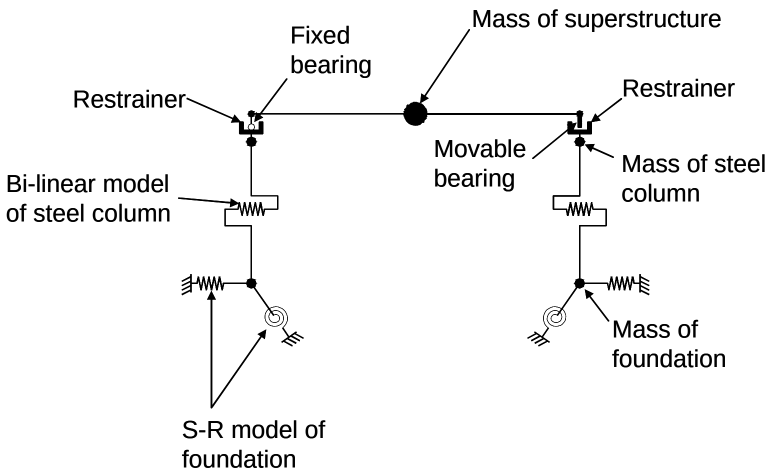



Figure 5 Analysis model

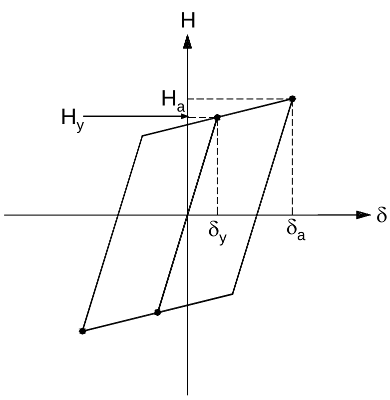



Figure 6 Analysis model of steel column

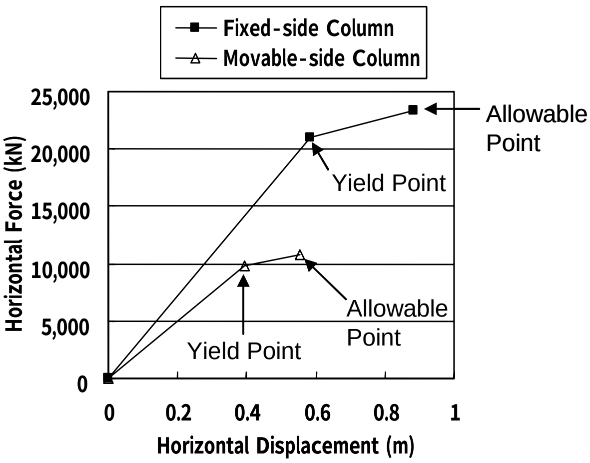



Figure 7 Push-over analysis of steel column

## 3. THE SEISMIC RESPONSE ANALYSIS

The seismic response analysis is conducted in the longitudinal direction. The analysis model is a non-linear frame model, shown in Figure 5. The foundation is modeled as the S-R model with the linear spring. The steel columns are the bilinear hysteresis models, shown in Figure 6. $H_y$ and $\delta_y$ are the yield force and displacement, respectively. $H_a$ and $\delta_a$ are the allowable force and displacement, respectively. These parameters are determined by the push-over analysis, shown in Figure 7. The allowable strength of the movable-side column is less than 50% of that of the fixed-side column. The allowable displacement of the movable-side column is about 60% of that of the fixed-side column.

Considering bearing failure, the fixed-side bearing is modeled in Figure 8. $H_F$ is the smallest yield strength of all the parts of the bearing. After the bearing failure, that is, the reaction force exceeds $H_F$, the performance of the bearing is assumed as Coulomb's friction law (Kajita et al. 1999). The after-failure friction coefficient is $\mu_S$. The vertical reaction

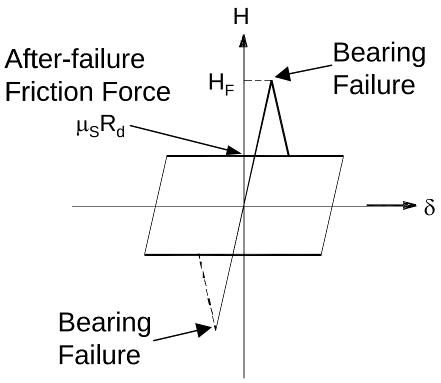



Figure 8 Analysis model of fixed bearing

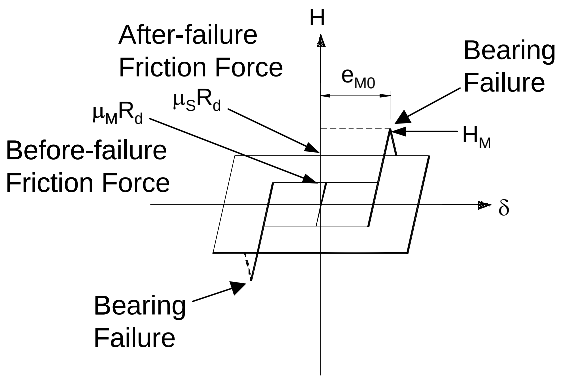



Figure 9 Analysis model of movable bearing

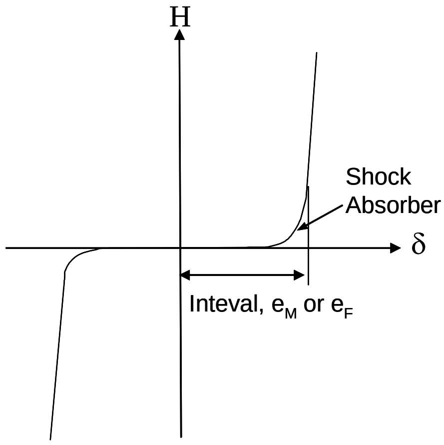



Figure 10 Analysis model of restrainer

Table 1 Strength of bearings, vertical reaction forces of bearing, and friction coefficients

| | Fixed Side | Movable Side |
|---|---|---|
| Yield Strength of Bearing (kN) | $H_F$=18,000 | $H_M$=6,000 |
| Vertical Reaction Force of Bearing $R_d$ (kN) | 22,500 | 22,500 |
| Friction Coefficient before Bearing Failure $\mu_M$ | - | 0.05 |
| Friction Coefficient after Bearing Failure $\mu_S$ | 0.2 | 0.2 |

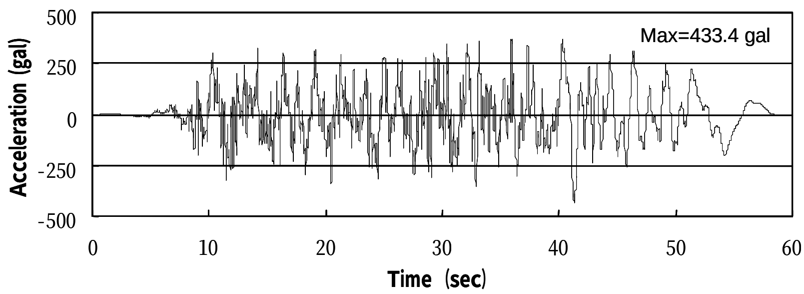



Figure 11 Input ground motion (JRA 2002)

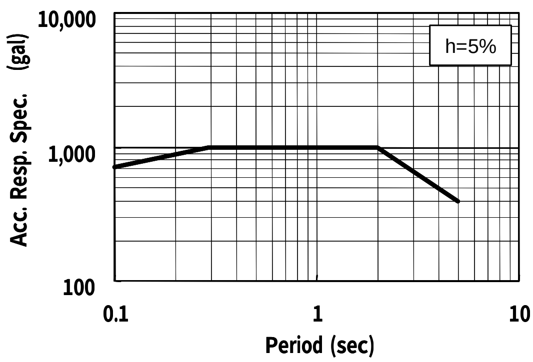



Figure 12 Acceleration response spectrum of input ground motion (JRA 2002)

force of the bearing is $R_d$. As is the case with the fixed bearing, the movable bearing is modeled in Figure 9. Before the failure, the movable bearing has a frictional force with the before-failure friction coefficient, $\mu_M$. The movable distance of the movable bearing is $e_{M0}$ (=0.15 m). $H_M$ is the yield strength of the stopper of the movable bearing. After the failure of the stopper, the performance of the movable bearing is assumed to be equal to the fixed bearing. The restoring force model of the restrainer is shown in Figure 10. There is no force of constraint within the interval, $e_M$ or $e_F$. The force of constraint works when the displacement exceeds $e_M$ or $e_F$. Since the rubber-type shock absorber is installed in the restrainer gap. The curve zone 100 mm is incorporated before the end of the gap.

Table 1 shows the strength of the bearings, the vertical reaction force of the bearings, and the friction coefficients before and after the bearing failure.

In this paper, the effects of the length of the restrainer gap to the bridge response are studied. The gap of the fixed-side restrainer, $e_F$ varies in the range of 0.1-1.0 m. The gap of the movable-side restrainer, $e_M$ varies in the range of 0.2-0.5m. In addition, the case of no restrainer is analyzed.

The input ground motion is shown in Figure 11, which is the standard strong ground motion on the soft ground by the subduction zone earthquake for the seismic design of the Japanese highway bridges (JRA 2002). The acceleration response spectrum of the input ground motion is shown in Figure 12.

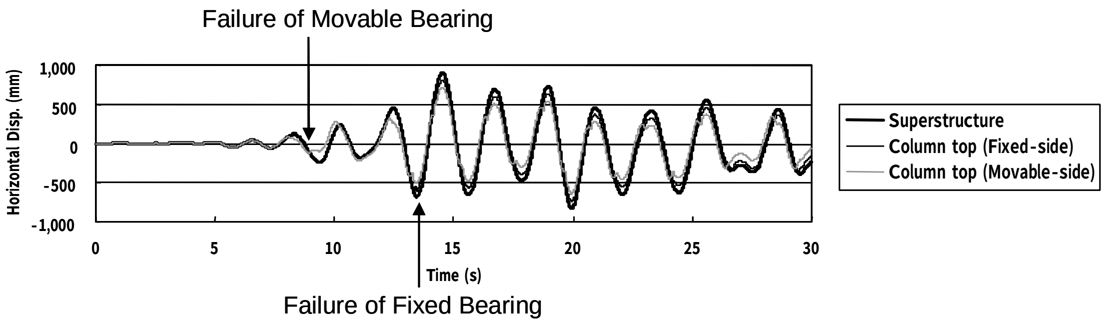



Figure 13 Horizontal displacement time history ($e_F$=0.1 m, $e_M$=0.2 m)

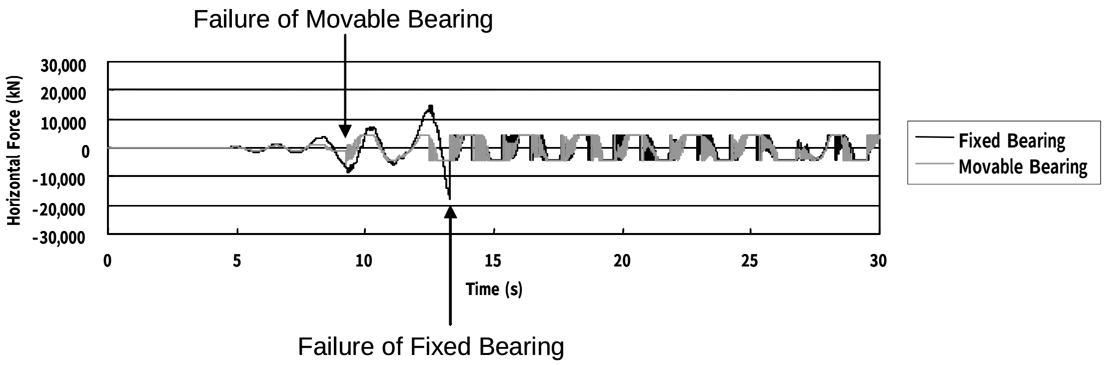



Figure 14 Horizontal force time history of bearing ($e_F$=0.1 m, $e_M$=0.2 m)

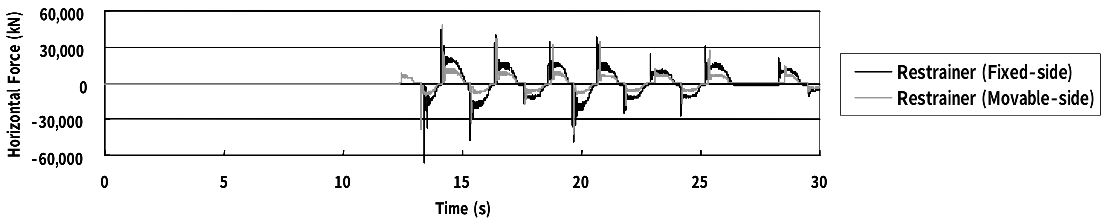
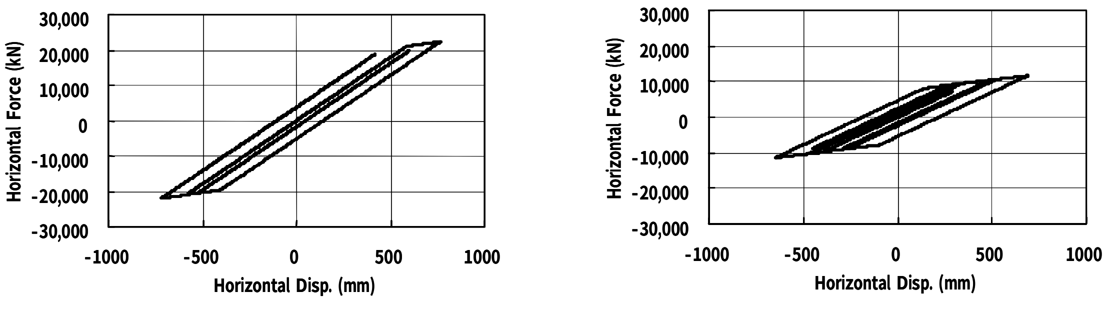



Figure 15 Horizontal force time history of restrainer ($e_F$=0.1 m, $e_M$=0.2 m)




(a) Fixed-side (b) Movable-side

Figure 16 Hysteresis loop of steel column ($e_F$=0.1 m, $e_M$=0.2 m)

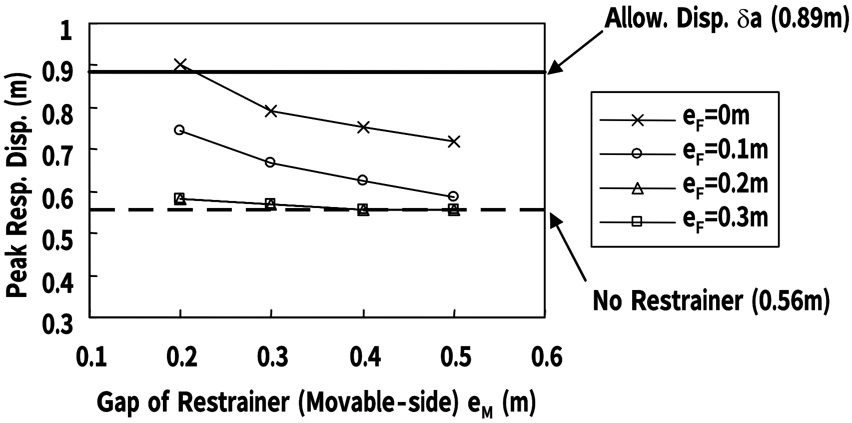


Figure 17 Peak response displacement of column top (Fixed-side), $\delta_{P1}$

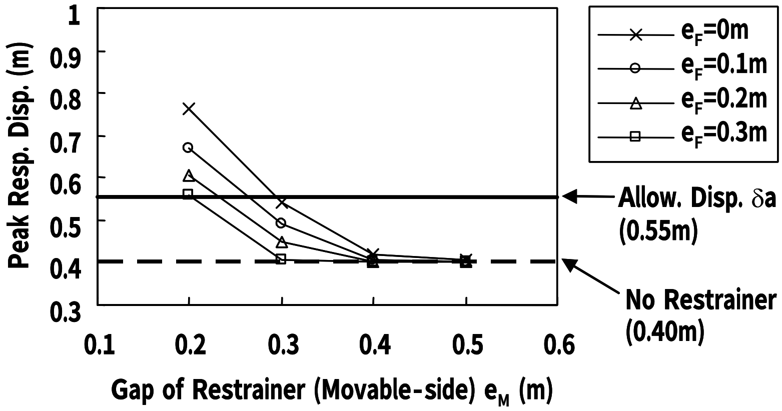


Figure 18 Peak response displacement of column top (Movable-side), $\delta_{P2}$

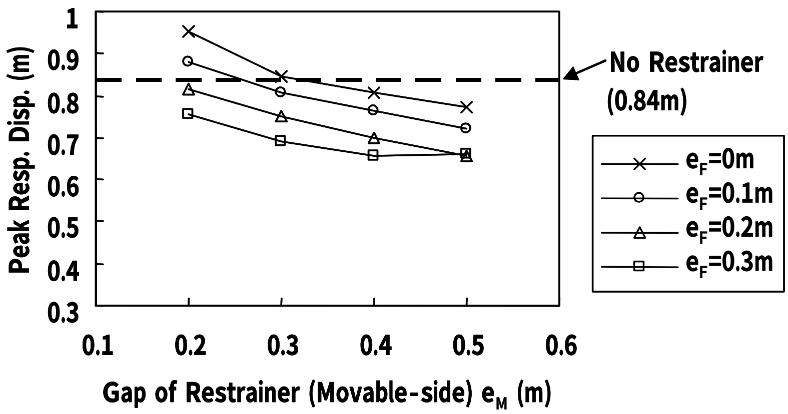


Figure 19 Peak response displacement of superstructure, $\delta_G$

## 4. RESULTS OF THE SEISMIC RESPONSE ANALYSIS

The time histories of displacements, bearing forces and restrainer forces in the case of the gap of the fixed-side restrainer, $e_F$=0.1 m and the gap of the movable-side restrainer,

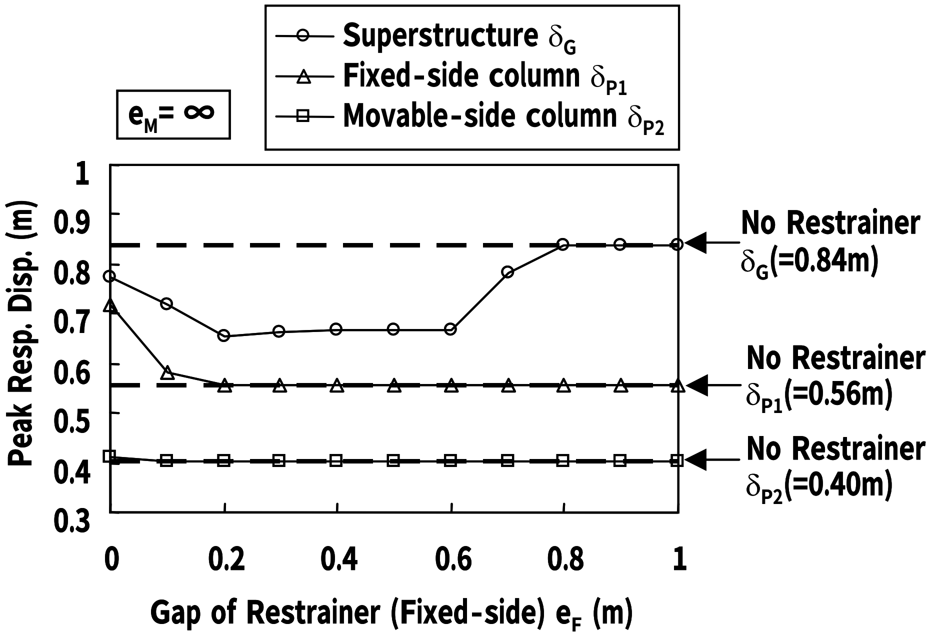



Figure 20 Peak response displacement of the superstructure, $\delta_G$ and the column tops, $\delta_{P1}$, $\delta_{P2}$

$e_M$=0.2 m are indicated in Figure 13, 14, 15, respectively. Figure 16 shows the hysteresis loop of the steel columns. The movable bearing fails at around 9 sec. The fixed bearing fails at around 13 sec. Both the fixed-side restrainer and the movable-side restrainer work actively after 13 sec. Both the fixed-side and movable-side steel columns go beyond their yield points into the plastic range.

Supposing the fixed bearing has a linear system, the peak horizontal force of the fixed bearing will be $H_R$ = 23,800 kN as against its yield strength $H_F$ = 18,000 kN. Thus, the fixed bearing is sure to be failed.

The peak response displacements of the fixed-side column top, $\delta_{P1}$ are shown in Figure 17. The lager the gap of the movable-side and fixed-side restrainers, $e_M$ and $e_F$ are, the smaller the $\delta_{P1}$ are. Except the case of $e_M$=0.2 and $e_F$=0 m, $\delta_{P1}$ are smaller than the allowable displacement $\delta_a$ (=0.89 m). As the $\delta_{P1}$ in the range of $e_M$>0.4 m and $e_F$>0.2 m are nearly equal to the $\delta_{P1}$ (=0.56 m) with no restrainer, the effect of the inertia force through the fixed-side restrainer is small in case of $e_M$>0.4 m and $e_F$>0.2 m.

The peak response displacements of the movable-side column top, $\delta_{P2}$ are shown in Figure 18. The $\delta_{P2}$ in case of $e_M$=0.2 m are larger than the allowable displacement, $\delta_a$ (=0.55 m), because the large inertia force through the small restrainer gap works on the movable-side column. On the other hand, the effects of the inertia force through the movable-side restrainer are small in case of $e_M$>0.4 m.

The peak response displacements of the superstructure, $\delta_G$ are shown in Figure 19. As $e_M$, $e_F$ increase, $\delta_G$ decrease. The reason is that the lager gap of the restrainer generates lager friction loss after the bearing failure. The $\delta_G$ in case of $e_M$=0.2 m go beyond the $\delta_G$ (=0.84 m) with no restrainer, because the excessive inertia force works on the movable-side steel column and the column has the over-allowable displacement.

Figure 20 shows the peak response displacements of the superstructure and the column tops in case of no restrainer in the movable side ($e_M=\infty$). The displacement of the superstructure, $\delta_G$ has minimal value when 0.2 m < $e_F$ < 0.4m.

## 5. CONCLUSION

The bearing fuse effect that is the seismic isolation effect after bearing failure is studied for the Hanshin Expressway existing arch bridge. The study shows that the peak response displacements decrease as the restrainer gaps increase because of the seismic isolation effect and the friction loss after the bearing failure. The large restrainer gap gives the arch bridge an advantage in terms of the seismic performance.

The movable-side steel column cannot afford its strength and ductility. If the restrainer gap on the movable side is small, the inertia force working on the movable-side column increases and the column top displacements may exceed its ductility capacity.

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