

PERFORMANCE OF MECHANICAL SEISMIC LOAD TRANSMISSION DEVICE BASED ON IMPACT

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SUMMARY

Multi-span continuous type bridges in moderate seismicity regions can be very vulnerable to the earthquake ground motion in longitudinal direction if they are not designed for the earthquake load. In this paper a mechanical seismic load transmission system is proposed that can distribute seismic load from piers with fixed support to the ones with movable support. The performance of this device was studied experimentally. The impact tests were performed to investigate the effects of impact to the connection, deck and pier. A small-scale continuous bridge model was constructed and tested on the shaking table. Both the un-retrofitted and retrofitted models were studied and their performance was compared. It was found that the proposed seismic load transmission system was very effective in reducing seismic demand on the individual bridge pier.

INTRODUCTION

The seismicity of Korea is considered to be from low to moderate level [1]. The earthquake resistance design requirement was included in the standard highway bridge specifications of Korea in 1992. Therefore the majority of the existing bridges do not have seismic details to provide adequate amount of ductility. The multi-span continuous bridges usually have one fixed support in longitudinal direction. In this type of bridges, the pier with fixed support should carry the entire seismic load coming from the superstructure in longitudinal direction. This excessive load can cause failure of bearings, falling down of bridge decks and damage to piers. In order to upgrade the seismic performance, the bearings need to be reinforced, the falling down of bridge decks should be prevented and the failure of piers should be avoided. There exist many currently available retrofit methods for the pier such as steel jacketing and

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wrapping with carbon and fiber-glass sheet [2, 3]. Alternatively seismic isolation systems, damping devices and shock transmission units can be employed. However, the damaging earthquake occurs infrequently in moderate seismicity regions. The return period is usually very long. It makes hard to justify the use of those conventional retrofit methods developed for the high seismicity regions in moderate seismicity regions.

In this paper a new retrofit system is proposed that is expected to be more economical than existing devices. The idea is using movable piers as shear keys in longitudinal direction. The seismic load from the super structure can be shared by the piers with movable supports though mechanical load transmission devices attached to the decks and piers. The performance of this device was studied experimentally [4, 5]. The impact tests were performed to investigate the effects of collision to the connection and to the pier concrete. A small-scale continuous bridge model was constructed and tested on the shaking table. The mechanism of the new system will be explained. The impact test results will be reported on the effects of impact to the connection and to the pier concrete and static test results will be addressed. Finally analytic and experimental studies on the performance of the systems will be compared. Since the proposed system is practically maintenance-free, it will be especially suitable in the region where the occurrence of earthquake is rare.

SEISMIC LOAD TRANSMISSION SYSTEM BASED ON IMPACT

The proposed mechanical seismic load transmission device is described in Figure 1. It is intended to be installed at the piers with movable support. The device consists of impactors attached to the bridge deck and stoppers anchored to the pier. The shock absorber is attached to the surface of the stopper. A sample bridge equipped with the system is shown in Figure 2. At a movable supports there will be gaps of prescribed amount between the impactor and the stopper to accommodate movement due to temperature change. When earthquake ground motion acts to the bridge, initially the seismic load in the longitudinal direction coming from the superstructure will be resisted by the piers with fixed and movable supports. If the load at movable support exceeds the friction force then the rest of the seismic load will be carried by the pier with fixed support. As the longitudinal displacement of fixed pier increases, the impactors at the movable supports will begin to contact the stoppers sequentially. Consequently many piers will participate in carrying the seismic load in longitudinal direction. One particular feature of the proposed device is that the impactor has curved surface. Therefore it can accommodated miss-alignment due to the construction error, temperature change and deformation within considerable amount of tolerance without developing stress concentration.



Figure 1. Mechanical seismic load transmission device

The increased seismic capacity of the bridge can be estimated easily using capacity diagram as illustrated in Figure 3. The energy dissipation will occur in three modes: viscous damping, friction at movable supports and hysteric damping under the cyclic loading if the individual pier deforms in inelastic range. The seismic capacity of the bridge with the proposed system can be much larger than the un-retrofitted one. However the overall system will become stiffer and the effective period will be shorter. This fact may lead to the increased seismic demand. The performance of the bridge with the proposed system can be estimated using capacity spectrum method.



(b) During earthquake





Figure 3. Behavior of a bridge with seismic load transmission device

IMPACT TEST OF SEISMIC LOAD TRANSMISSION DEVICE

When the impactor at the deck collides with the stopper at the pier, a large amount of impact load may be exchanged between them. The most vulnerable one will be the connection system between the impactor and the superstructure. The impact load may cause failure of the anchorage system, local damage to the deck slab or girder. In order to study the safety margin of the connection system, impact tests were designed and performed.

Impact test model [4]

A 4-span continuous bridge was selected as the prototype for the impact test model. The span length was assumed to be 40m. The impactors were assumed being connected to the bottom slab of RC box girder. The T-shape solid circular pier had cap beam. The height of the pier was assumed to be 15m and the diameter 3.5m. The weight of the super structure was 30tonf/m. The geometric scale factor was 6 and velocity scale factor was 1. The cap beam was modeled as concrete block. And it was supported by the springs simulating the flexibility of the pier. The stiffness of the spring was determined to be equivalent to the effective elastic stiffness of the pier. The superstructure was modeled as steel blocks mounted on and firmly fixed to a cart rolling down the sloped railway. A RC slab model was fixed to the frame of the cart. The steel impactor was anchored to the RC slab. The maximum weight of the impactor was measured using photo-electric sensor. Acceleration time histories were measured at the impactor and the stopper and strains at the anchors and concrete slabs. The impact force was measured using load cells installed between the spring and the reaction frame. This force represents base shear acting on the pier. The concept of the test setup is described in Figure 5 (a). Figure 5 (b) is the photo of the impact test apparatus.



Figure 4. Test model

Impact test results [4]

Tests were repeated for the various values of velocity. The impact velocity was controlled by changing the elevation of the cart at the starting position. The range of the impact velocity was estimated from the analytical study results to be between the 0.2m/s and 0.6m/s.

The response histories at the impact velocity 0.5m/s are provided in Figure 6, 7, and 8, respectively for displacement of cap beam (pier), spring force (base shear) and acceleration of impactor. With impact velocity 0.5m/s, the maximum displacement was 6.1mm. The yield displacement was estimated to be 6.0mm. The peak values of the response at various impact velocities are summarized in Table 1. When the effective peak ground acceleration is 0.3g, the peak impact velocity is estimated to be less than 0.6m/sec.

At this level of impact velocity, there was no indication of damage to the anchorage and RC slab. Only when the velocity reached 0.7m/sec, there occurred cracks to the concrete slab followed by the anchorage failure. Since the PGA of maximum credible earthquake is estimated to be less than 0.3g in Korea, this load transmission device can be used in real application.



(a) Schematic view



(b) Photo of test set-up

Figure 5. Test set-up





Figure 7. Load time history





Table 1. Summar	y of	impact	test	results
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Velocity	Max. acc. at device (g)	Max. acc. at cap beam (g)	Max. load (kgf)	Max. displ. (mm)
0.31 m/s	14.5	0.4	4582	3.5
0.40 m/s	35.1	1.2	8815	5.0
0.50 m/s	44.8	8.9	11424	6.1
0.70 m/s (Failure)	56.0	13.4	16620	8.2

SEISMIC PERFORMANCE TEST OF BRIDGE MODEL EQUIPED WITH SEISMIC LOAD TRANSMISSION DEVICE

Small scale bridge model [5]

Shaking table tests of scaled bridge model were performed to study the improvement of seismic performance with the mechanical seismic load transmission system. The prototype bridge was a 4-span continuous bridge of which span length was 40m. The super structure was steel box girder. The movement in longitudinal direction was restrained by a single pier with fixed support. The RC pier had solid circular section with 3.5m diameter. The height was 14m. The scale factor 8 was chosen to take into account the capacity of shaking table. Mechanical and material properties are compared in Table 2.

Properties		Prototype	Model (Scale 1/8)
Material strength	Concrete	24	24
(MPa)	Rebar	300	300
Dimension of pier	Diameter(m)	3.5	0.4
	Height(m)	14	1.9
Longitudinal	Diameter(mm)	25	10
reinforcement	Ratio(%)	0.52	1.25
Transverse reinforcement	Diameter(mm)	19	3
	Spacing	200	30
	Ratio(%)	0.344	0.26

Table 2. Summary of impact test results

Shaking table test [5]

Figure 9 shows the bridge model mounted on the shaking table. The total weight of the test model was 20 tons. The details of device are shown in Figure 10. The tests were performed for the various values of the gap between the impactor and the stopper. The gap was adjusted by adding or deleting steel plate in Figure 11. The rubber plate was used as the shock absorber. In the present test model the stiffness of the rubber plate was 0.7 MPa. Strain gauges were attached to the longitudinal reinforcement bars of the pier. The deformation of the pier was measured using clip gauges to identify the plastic hinge region. Transducers were deployed to measure the relative displacement between each pier and the superstructure. Acceleration time histories were measured at the impactors and at the superstructure. The scaled 1940 El Centro ground motion was used as the input table motion.



Figure 9. Photo of shaking table test



Shaking table test results [5]

Behavior of bridge model with seismic load transmission system

The time histories of relative displacement at the piers with fixed and movable supports of the unretrofitted model are compared in Figure 11. The responses of the model equipped with the new system are compared in Figure 12. The PGA of input motion was 1.2 g. The gap size for the retrofitted model was 0.0mm. In the case of un-retrofitted model the difference in relative displacement was quite large. On the other hand the pier displacements were almost identical in the case of retrofitted model. It indicates that the mechanical seismic load transmission system was working effectively



Un-retrofitted bridge model

Figure 12. Response displacement of retrofitted bridge model

Natural frequency

The dominant frequencies of the model with and without the system were identified from the Fourier spectrum of the displacement responses. The value without transmission system was 2.3 Hz. The value with the system was 2.4 Hz, 2.6 Hz and 3.5 Hz, for the gap size 6 mm, 2 mm and 0.0 mm, respectively. As the gap size became smaller, the overall system became stiffer and the effective period became shorter.

Maximum relative displacements

The maximum relative displacements of the model with and without the system were measured at the pier with fixed support and compared in Figure 13. The maximum displacement decreases when the proposed system was utilized. The maximum reduction was achieved with the gap size 4mm. As the gap size becomes smaller, the effective period will be shorter. This fact may lead to the increased seismic demand and may explain the reason why the minimum displacement did not occur when the gap size was the smallest.



Figure 13. Relation of max. response displacement v.s. gap size

Peak acceleration

The peak acceleration of the impactor were measured and plotted with respect to the gap size in Figure 14. When there was no gap, the impact effect was negligible. When the gap size had finite value, the impact acceleration became very high. However, if converted for the prototype model, the value would not be considered as severe as to cause damage to the connections between the impactor and superstructure.

Even though the relative displacement had minimum value at the 4 mm gap size, the zero gap size is preferable to minimize the adverse impact effects. Figure 15 shows the acceleration time history of the impactor when the gap size was 4mm.



CONCLUSIONS

Multi-span continuous type bridges in moderate seismicity regions can be very vulnerable to the earthquake ground motion in longitudinal direction if they are not properly designed for the earthquake load. In this paper a mechanical seismic load transmission system is proposed that can distribute seismic load from piers with fixed support to the ones with movable support. The performance of this device was studied experimentally.

Impact test results indicated that local failure at the connections with bridge decks may not be serious problem if the intensity of earthquake is of moderate level. Hence the system can be applicable to the seismic upgrading of bridges in moderate seismicity regions such as Korea.

Shaking table test results demonstrated that the new transmission system increases definitely the seismic capacity of a bridge and improves its seismic performance. It was confirmed also that the impact load could not be a constraint in real application.

Since the proposed system is practically maintenance-free, it will be especially suitable in the region where the occurrence of earthquake is rare.

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