

Use of Shock Transmission Units in the Puyan Interchange of the National Freeway (Sections Open to Traffic) Bridge Seismic Retrofit Project (Phase 1)

AUTHORS : LIN BING-SONG¹ WANG-JI-SHAN² LIN SHENG-FA³

- 1. Ministry of Transportation and Communications, Taiwan Area National Freeway Bureau Team Leader**
- 2. Ministry of Transportation and Communications, Taiwan Area National Freeway Bureau Section Chief**
- 3. Ministry of Transportation and Communications, Taiwan Area National Freeway Bureau Engineer**

SUMMARY

The National Freeway (sections open to traffic) Bridge Seismic Retrofit Project (Phase 1), which encompasses the assessment and retrofitting of the whole Zhongshan Freeway, is the first, large-scale freeway bridge seismic retrofit project in Taiwan. At the Puyan System Interchange (STA.207K+600), 4 fly-over ramps cross the Zhongshan Freeway. Some of the ramp piers and their foundations are very close to the Zhongshan Freeway piers and foundations and parts of the foundations of the ramps are directly beneath the freeway itself. Therefore, there were some formidable space limitations for seismic retrofitting work. Considering the space limitations and the need to increase the static indeterminacy and to better disperse earthquake loads from the substructure of the interchange, shock transmission units (STUs) were selected for the seismic retrofit project. STUs have already been implemented in many projects around the world, including railway bridge seismic retrofit projects in Taiwan and abroad as well as bridge seismic retrofit projects overseas. STUs were selected for use in this freeway seismic retrofit project based on site restrictions and the characteristics of STUs. This paper aims to use the 4 flyover ramps of the Puyan System Interchange (STA.207K+600) that cross the Zhongshan Freeway to outline the design, testing, construction, maintenance, and other relevant aspects of the STUs, to share the experience with the engineering community, and to aid the design and construction of future bridge seismic retrofit projects.

1. PREFACE

On September 21, 1999 Taiwan was hit by an earthquake measuring 7.3 on the Richter Scale with a maximum intensity of level 6 and a peak ground acceleration of 989gal. The epicenter of the earthquake was located at Jiji, Nantou County. Because the National Freeways of Taiwan are the main arteries connecting the north and the south, they have a great influence in the economic development and daily lives of Taiwan and its citizens. Fortunately, the National Freeways were not severely damaged in this earthquake. As a precaution, the Taiwan Area National Freeway Bureau is actively developing a complete plan for the seismic retrofitting of bridges for sections open to traffic of the Zhongshan Freeway and National Freeway No. 2. The Bureau is also actively re-inspecting and re-assessing both old and new bridge structures along the freeways in hopes of reducing structural damage, reducing casualties, and successfully providing an emergency relief lifeline in the aftermath of future earthquakes.

The National Freeway (sections open to traffic) Bridge Seismic Retrofit Project (Phase 1), more specifically the seismic assessment and retrofit of the whole Zhongshan Freeway, was the first section to have the aforementioned plan implemented and the first, large-scale freeway bridge seismic retrofit project in Taiwan. The Taiwan Area National Freeway Bureau commissioned T.Y. Lin International Taiwan to carry out the seismic retrofitting design of the project. The project aims to improve the seismic capacity of Zhongshan Freeway and to create a disaster response road, a lifeline, from northern to southern Taiwan.

Dampers, shock transmission units, and other anti-seismic devices are typically utilized in railway projects, high speed rail projects, and rapid transit projects and are seldom used for freeway projects. However, in order to overcome space constraints of the construction sites, anti-seismic devices were utilized in freeway bridge seismic retrofitting projects. For example, the cross passage bridge of the Neili Interchange (STA.56K+980) utilized fluid viscous dampers and the ramps of the Puyan System Interchange (STA.207K+600) utilized shock transmission units. By using these devices, the traffic impact on Zhongshan Freeway caused by seismic retrofitting work was reduced while accomplishing the goal of improving the seismic capacity of the bridges. The project can also serve as a reference for the design and construction of future seismic retrofit projects. The following details the design, testing, construction, and maintenance of the STUs used in the Puyan System Interchange (STA.207K+600).

2. SHOCK TRANSMISSION UNIT

STUs consist mainly of internal fluid and anchorage facilities and are installed between the superstructure and substructure of the bridge. The main function of STUs is to use the damping force of the fluid to absorb instantaneous earthquake forces and create a rigid link between superstructure and substructure, producing a lock-up effect.

When dynamic loads induced by vehicular braking or ground motion (earthquakes) occur, shock transmission units will come into use. The substructure (STU links the superstructure and substructure) locks up and effectively becomes a rigid link, which allows the strength of the superstructure to be passed onto the substructure. However, under slowly applied loads, such as temperature, shrinkage, or creep, the devices only provide a slight resistance ($\leq 10\%$ of the design load) so that the structure can freely move (Figure 1).

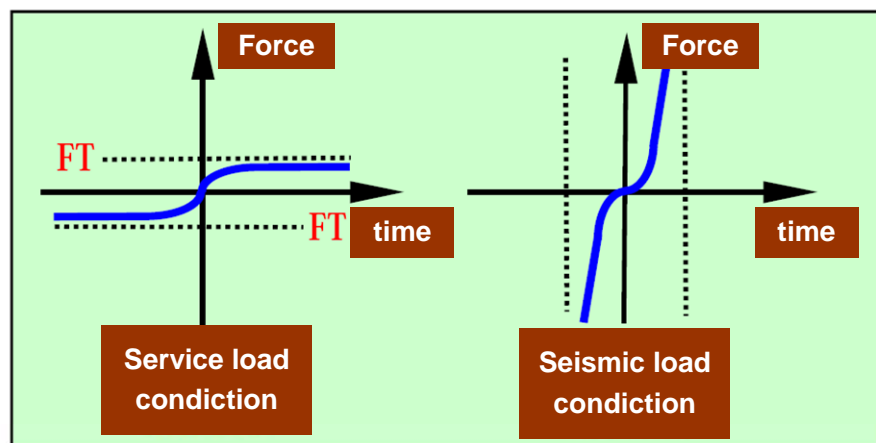


Figure 1 Time Curve of STU under Service Load and Seismic Load

An STU is mainly composed of two chambers and a piston (Figure 2). The chambers are filled with silicone-based fluid, which can flow between the left and right chambers under the control of the piston. The special silicon fluid that fills the STU is fairly stable and has an operating temperature range of -40°C to 50°C.

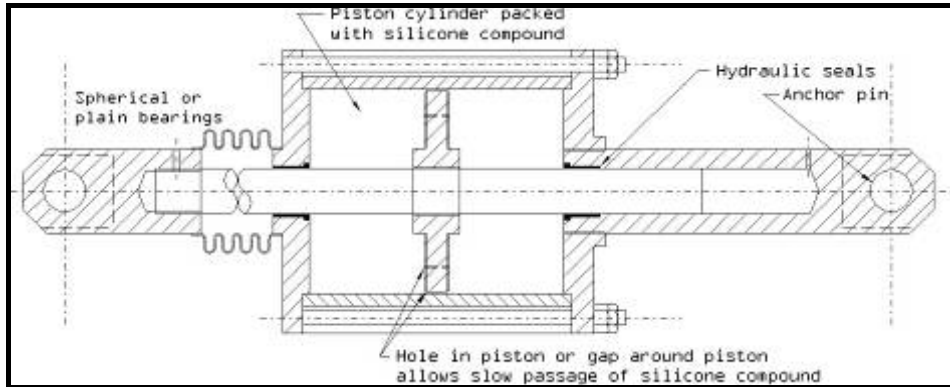


Figure 2 Shock Transmission Unit Schematic Diagram

3. BRIDGE SPECIFICATIONS AND SEISMIC DESIGN

3.1 Bridge Specifications

Puyan System Interchange Ramp 1, Ramp 3, Loop Ramp 1, and Loop Ramp 2 cross Zhongshan Freeway. Each of the four ramps are 75+120+75=270m long, are pre-stressed box beam bridges, and are 8.5m wide (Figure 3). The two middle piers are different in that one is a rigid support while the other is a moveable support (Figures 4~5, in the figures M represents a movable support, R represents a rigid support). Therefore, practically all of the longitudinal earthquake forces the 270m long vibration units would be subjected to would be taken by the single rigid support. The results of the assessment show that the foundations of the vibration units have insufficient strength to resist seismic forces and need seismic reinforcement.

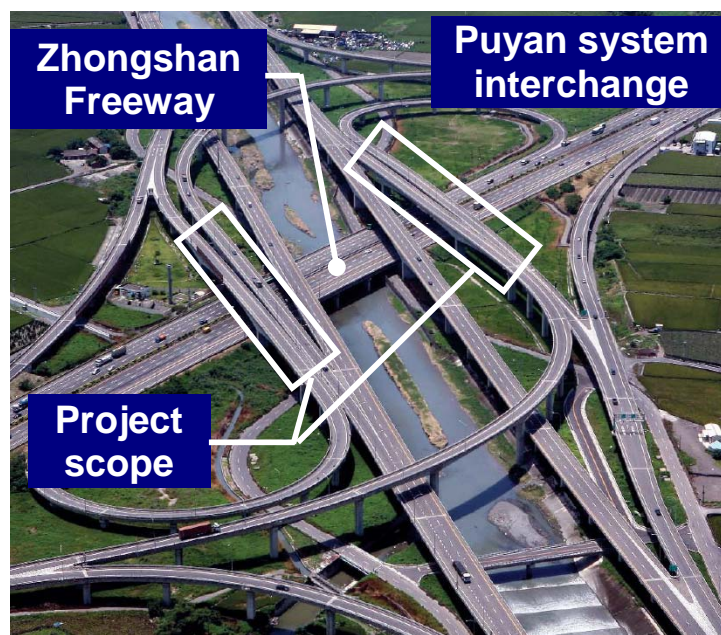


Figure 3 Project Scope Plan View

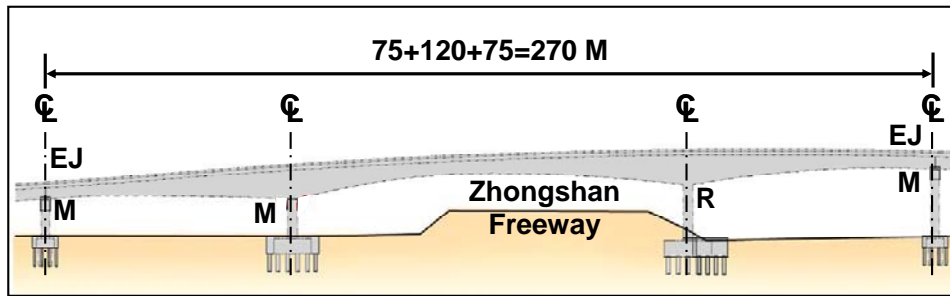


Figure 4 Bridge Elevation View

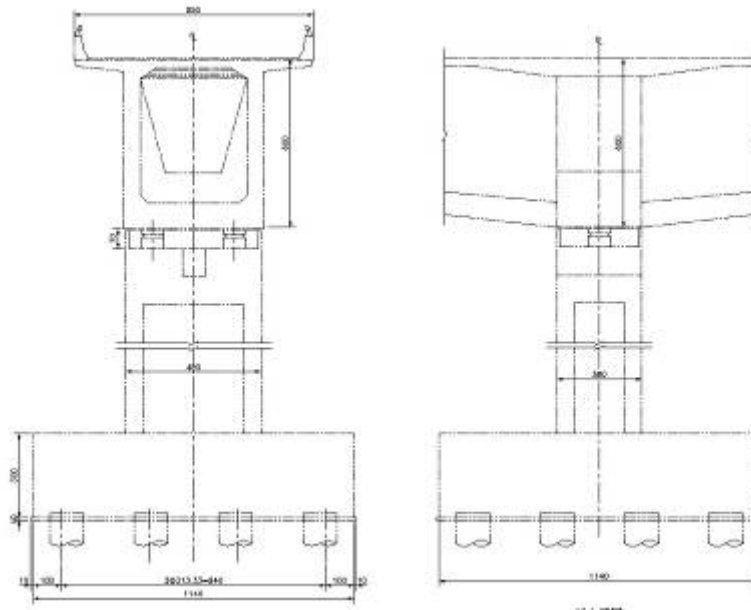


Figure 5 Middle Moveable Pier Front and Elevation View

3.2 Seismic Retrofit Design

During seismic retrofitting of the four bridges, there were formidable space constraints due to the close proximity of the pier foundations to adjacent pier foundations and parts of the pier foundations being beneath Zhongshan Freeway itself. Considering the space constraints and the need to increase the static indeterminacy and to better disperse earthquake loads from the substructure, STUs were installed on the moveable supports (Figures 6~7) and pier foundations were enlarged with new piles being added. The advantage of using STUs is that they do not change the existing conditions of the system in the long run. Therefore, temperature, shrinkage, and creep load have minimal impact on the bridge. At the same time, in the event of an earthquake the longitudinal earthquake forces will be shared by the two middle piers, increasing the static indeterminacy of the system and reducing the risk of damage to the bridge.

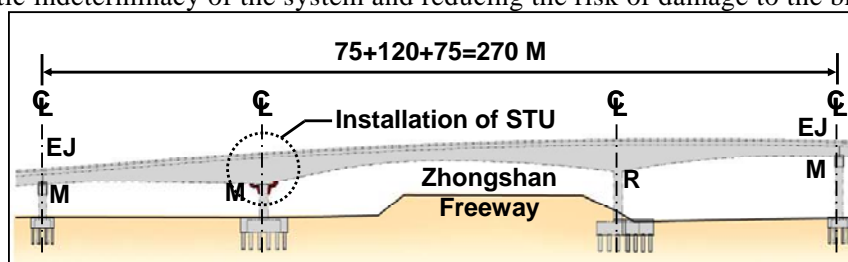


Figure 6 Bridge Seismic Retrofit Elevation View

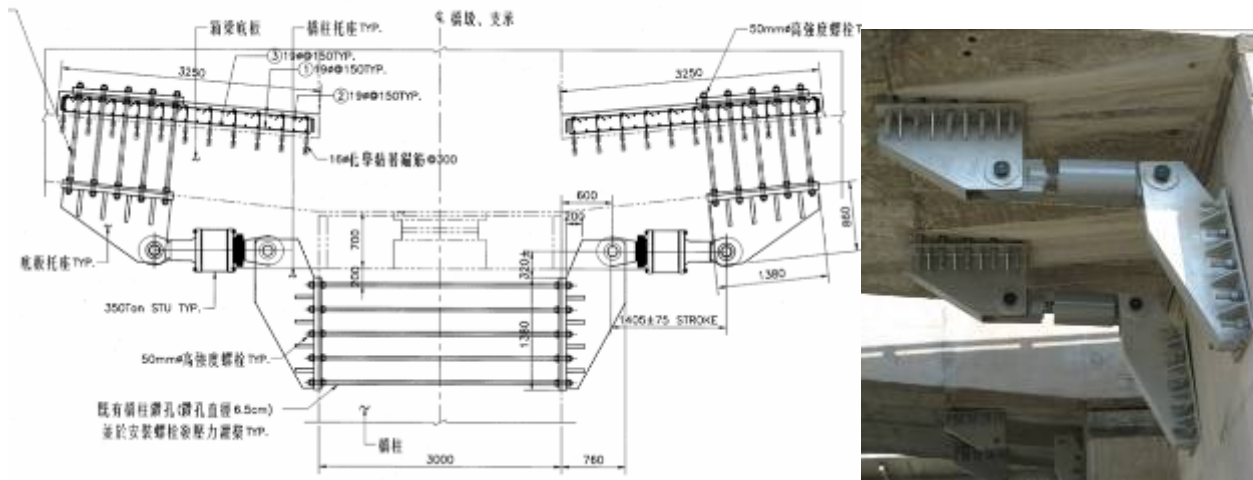


Figure 7 Shock Transmission Units installed on the Middle Moveable Piers

This project uses STUs that meet the following design and test requirements:

- A. Operating Temperature : 0~50°C
- B. Max. Drag Force : 10% of maximum earthquake load
- C. Max. EQ Force : 350 T/unit (4 units per pier)
- D. Total Displacement : $\pm 75\text{mm}$.
- E. Max. Dynamic Load Displacement : $\pm 12\text{mm}$ (at maximum earthquake load)
- F. Slow Movement Velocity : 6.5 mm/hr
- G. Fast Travel Rate : 2.0 mm/sec

4. SHOCK TRANSMISSION UNIT INSPECTION AND TEST SPECIFICATIONS

The materials of each structural element, tests, construction, maintenance, and all relevant aspects of the Shock Transmission Units (STU) will adhere to Section 32 of AASHTO LRFD Bridge Construction Specifications (2002). Tests include the following:

4.1 Prequalification Tests

The primary purpose of Prequalification Tests, also known as System Characteristic Tests, is to test the performance and fundamental properties of the STU. The proposed Shock Transmission Unit is the ALGASISM STU, which the Manufacturer fabricated in accordance with Section 32.4.1 of the aforementioned AASHTO specifications. This STU has already been widely used and have proven to be effective in projects around the world, including Section C295 of Taiwan's High Speed Rail (2001), Neihu Line of the Taipei Metro (2005), and other important projects in Taiwan.

4.2 Prototype Tests

The purpose of the Prototype Tests is to test the performance of the STUs and to determine if the STUs meet the design requirements specified in the design drawings. The tests and results are as follows:

A. Hydrostatic Pressure Test

- (1) **Purpose:** To verify the structural integrity of the STU and reliability of the sealing system under high internal pressure conditions.
- (2) **Test Method:** The STU shall be tested at 150% of its maximum computed internal pressure for at least 3 minutes. The initial and final pressure readings shall be recorded.
- (3) **Qualification Standard:** No signs of leakage under pressure. Hydrostatic pressure shall not drop more than 5% during the test.
- (4) **Test Results:** Under maximum load, the maximum internal pressure was 506 bar. At 150% of the maximum internal pressure the STU was pressurized and sealed for the duration of the test (Figure 1).

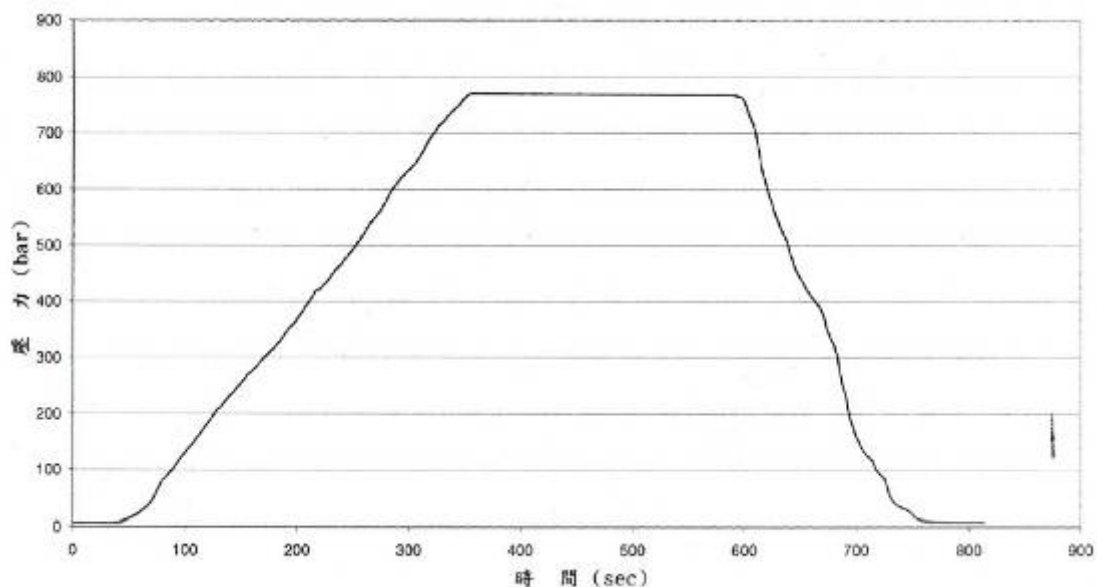


Figure 1 Hydrostatic Pressure over Time

B. Slow Movement Test

- (1) **Purpose:** To verify the STU will not impede the expansion of the structure under slow, long-term displacements.
- (2) **Test Method:** The STU shall be cycled for three complete and continuous cycles of with a maximum stroke equal to $\pm 75\text{mm}$ at a velocity of 0.01mm/sec . A continuous plot of the load and deflection shall be recorded.
- (3) **Qualification Standard:** No signs of leakage under operation. The force required to cycle the unit shall not exceed 10% of the nominal rated force and the device shall not lock-up during the test.

(4) **Test Results:** After three cycles at a velocity of 0.01mm/sec with a stroke of ± 75 mm, the maximum positive load was 68kN and the maximum negative load was -39kN. The reaction of the device was lower than the 350kN limit and it did not lock-up.

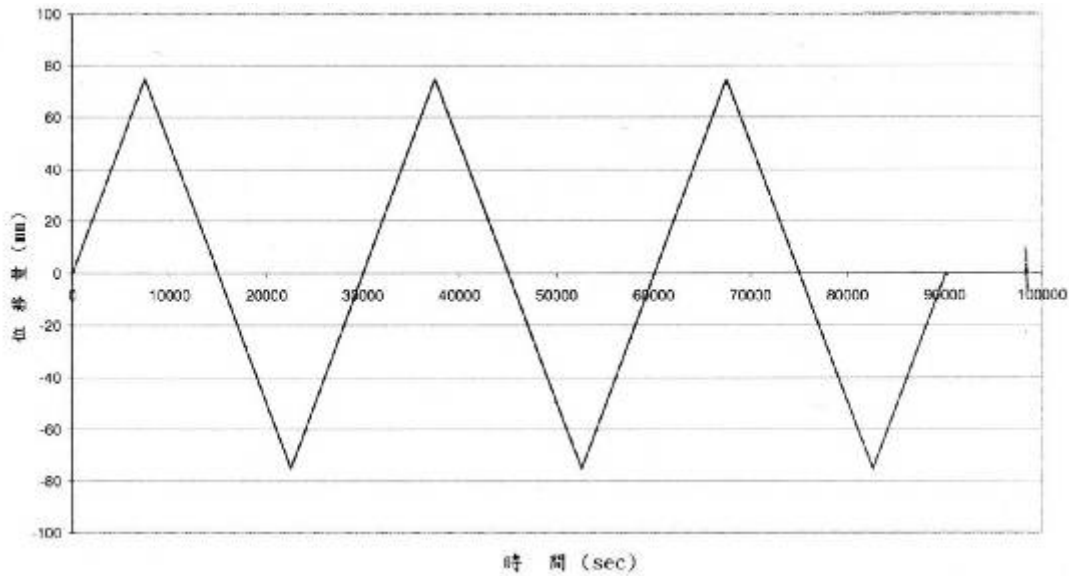


Figure 2 Deflection over Time for Slow Movement Test

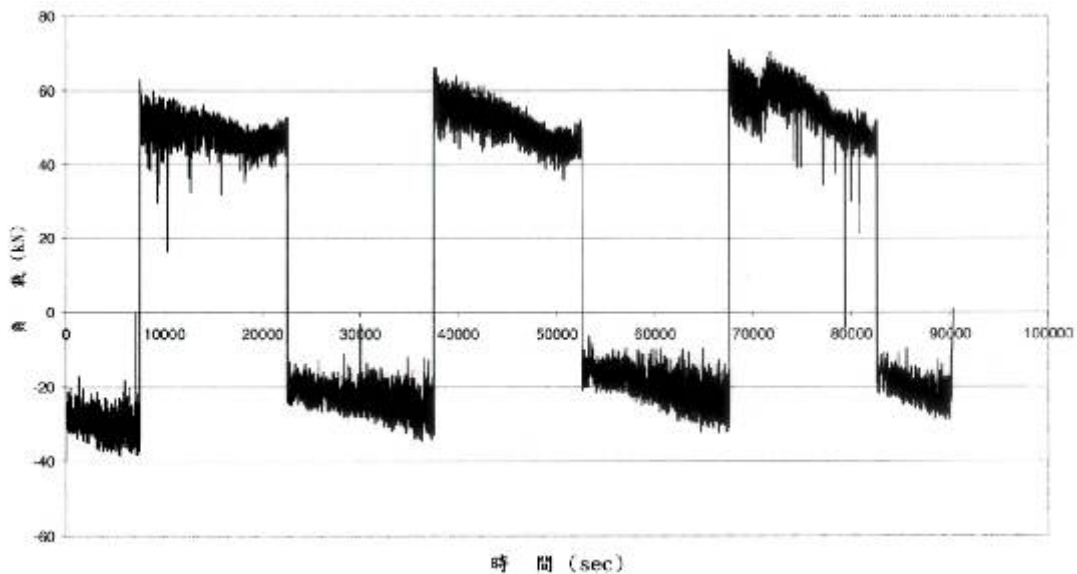


Figure 3 Load over Time for Slow Movement Test

C. Fast Movement Test

- (1) **Purpose:** To verify the STU will lock-up under sudden, fast displacements.
- (2) **Test Method:** The STU shall have the full nominal rated force applied to it at a fast travel rate (2mm/sec). The device shall be tested in both tension and compression but testing need not be cyclic. A continuous plot of load and deflection shall be recorded.
- (3) **Qualification Standard:** The device shall lock-up within 12mm and there shall be no signs of

leakage or binding. The stiffness of the STU from lock-up to maximum test load shall not vary by more than 10%.

- (4) **Test Results:** The STU had the full nominal rated force equal to 3500kN applied within 2 seconds. Compression (Figures 4~5) and tension (Figures 6~7) tests were carried out. Lock-up deflection under compression and tension were 3.64mm and 3.66mm respectively, which were both less than the required 12mm. There were no signs of leakage or binding during the test.

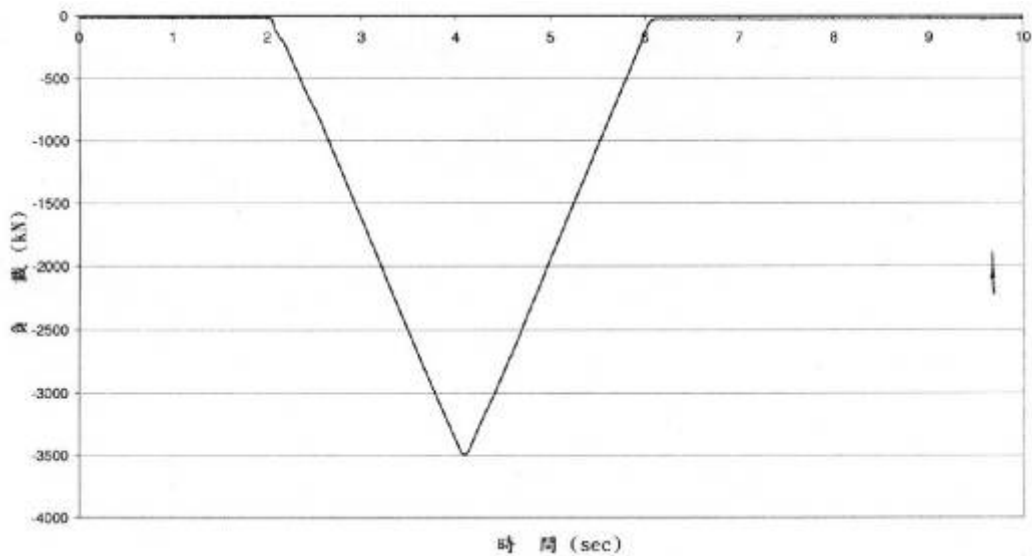


Figure 4 Load over Time for Fast Movement Test (Compression)

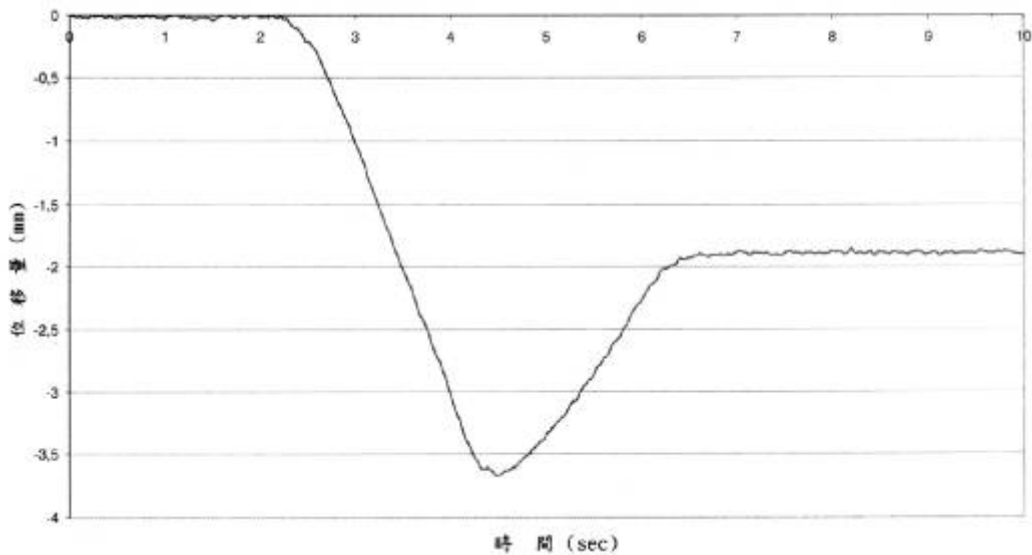


Figure 5 Deflection over Time for Fast Movement Test (Compression)

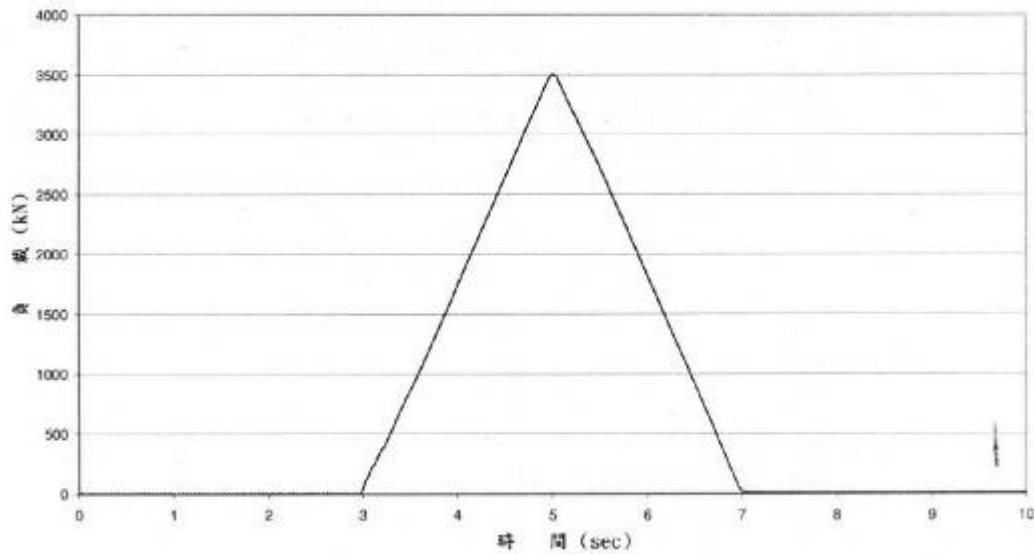


Figure 6 Load over Time for Fast Movement Test (Tension)

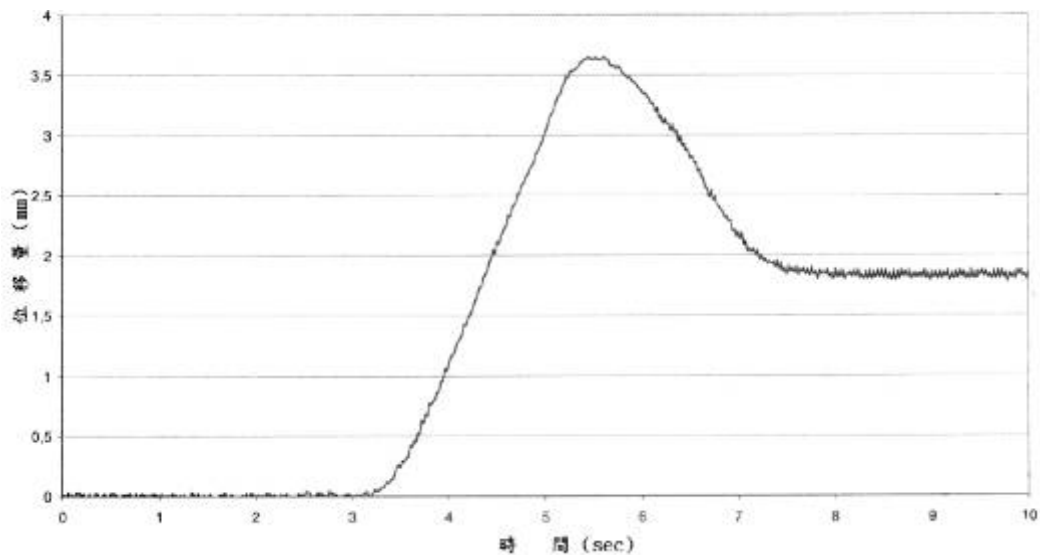


Figure 7 Deflection over Time for Fast Movement Test (Tension)

D. Simulated Dynamic Test

- (1) **Purpose:** To determine the STU will lock-up during dynamic loads.
- (2) **Test Method:** Each unit will have a tension force applied in less than 0.5 seconds, which will be sustained for a period of 5 seconds. After the tension load, a compression load is applied within one second, which will also be sustained for 5 seconds. The tension and compression loads shall be equal and will be at least three times the lock-up force determined in the Fast Movement Test but no more than the nominal rated force. A continuous plot of force versus deflection shall be recorded.
- (3) **Qualification Standard:** Deflection of the device shall not exceed 12mm between the point of zero load and the point of maximum load. Deflection under the sustained load portion of the test also shall not exceed 12mm.
- (4) **Test Results:** During the test, a tension force of 3500kN was applied in less than 0.5 seconds and

sustained for 5 seconds. A compression load of 3500kN was then applied within one second and also sustained for 5 seconds (Figures 8~9). Under tension, deflection at maximum load was 3.26mm and deflection during the sustained load portion of the test was 5.55mm. Under compression, deflection at maximum load was 4.22mm and deflection during sustained load was 6.08mm. All results were within the 12mm limit. There was no leakage or binding during the tests.

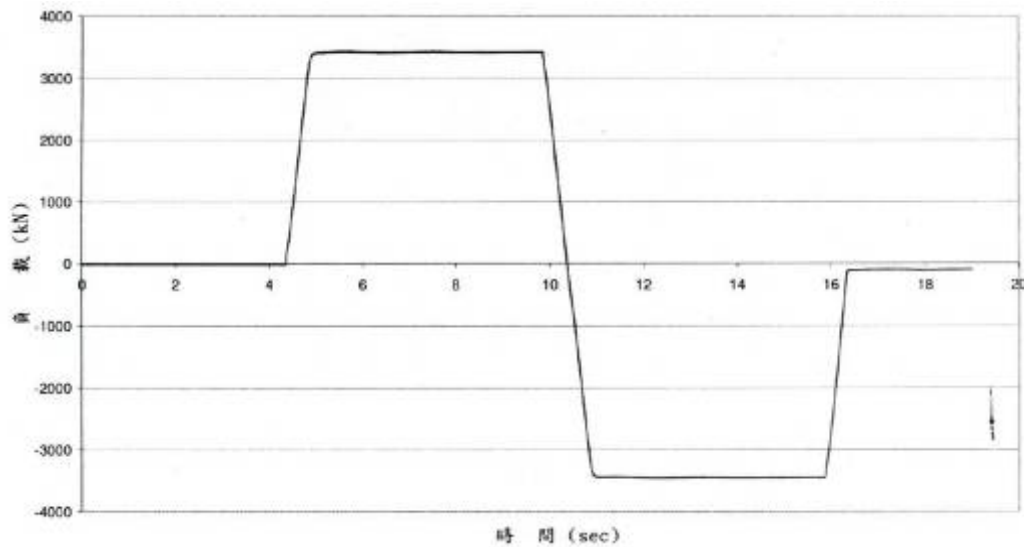


Figure 8 Load over Time for Simulated Dynamic Force Transfer Test

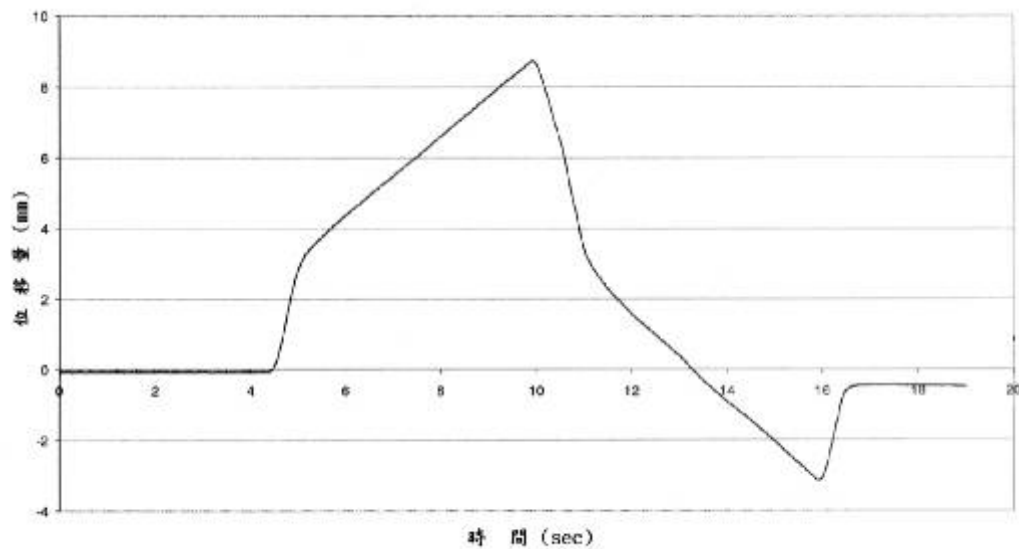


Figure 9 Deflection over Time for Simulated Dynamic Force Transfer Test

E. Overload Test

- (1) **Purpose:** To determine the STU will lock-up during dynamic loads.
- (2) **Test Method:** Each unit will have a tension force applied in less than 0.5 seconds, which will be sustained for a period of 5 seconds. After the tension load, a compression load is applied within one

second, which will also be sustained for 5 seconds. The tension and compression loads shall be equal and will be at least three times the lock-up force determined in the Fast Movement Test but no more than the nominal rated force. A continuous plot of force versus deflection shall be recorded.

(3) **Qualification Standard:** Deflection of the device shall not exceed 12mm between the point of zero load and the point of maximum load. Deflection under the sustained load portion of the test also shall not exceed 12mm.

(4) **Test Results:** During the test, a tension force of 3500kN was applied in less than 0.5 seconds and sustained for 5 seconds. A compression load of 3500kN was then applied within one second and also sustained for 5 seconds (Figures 8~9). Under tension, deflection at maximum load was 3.26mm and deflection during the sustained load portion of the test was 5.55mm. Under compression, deflection at maximum load was 4.22mm and deflection during sustained load was 6.08mm. All results were within the 12mm limit. There was no leakage or binding during the tests.

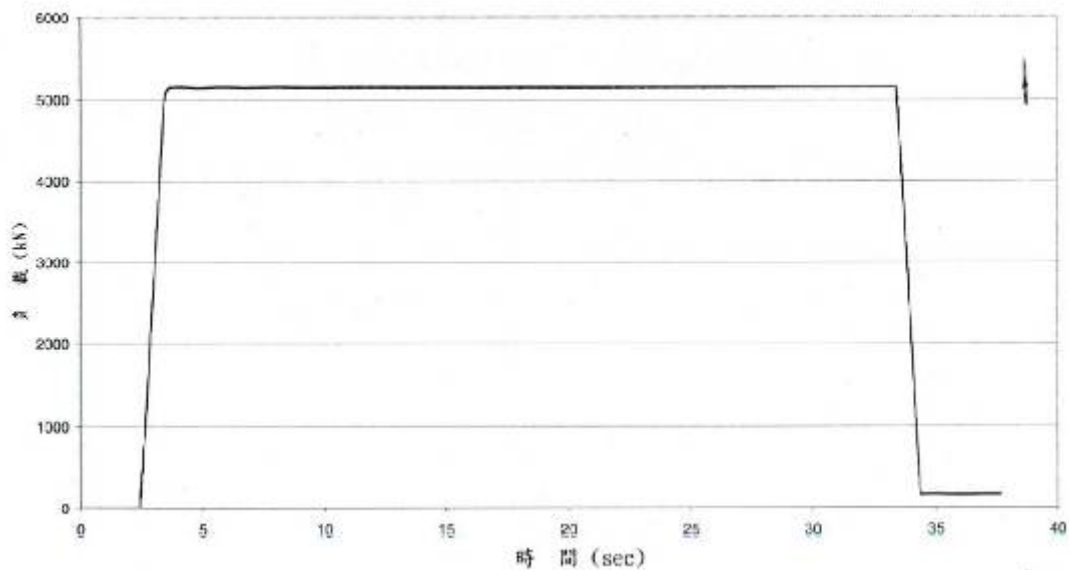


Figure 10 Load over Time for Overload Test

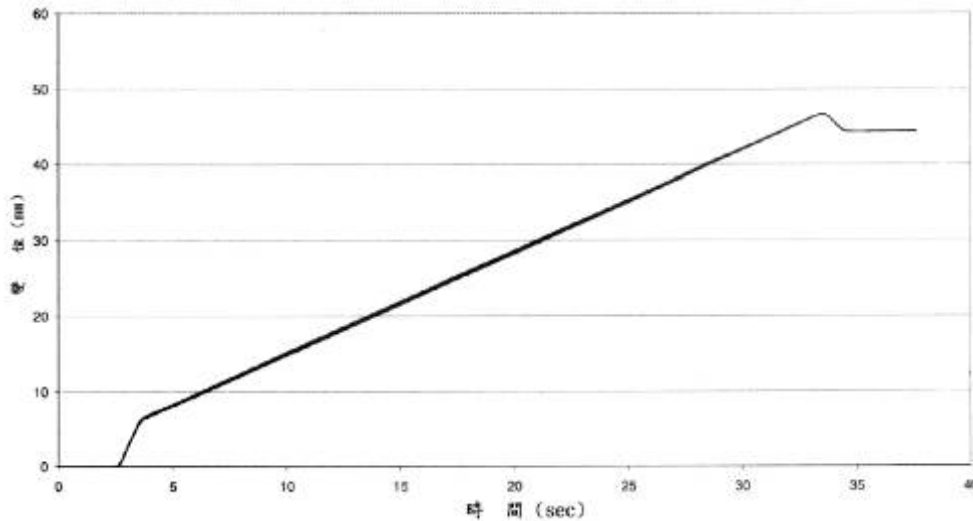


Figure 11 Deflection over Time for Overload Test

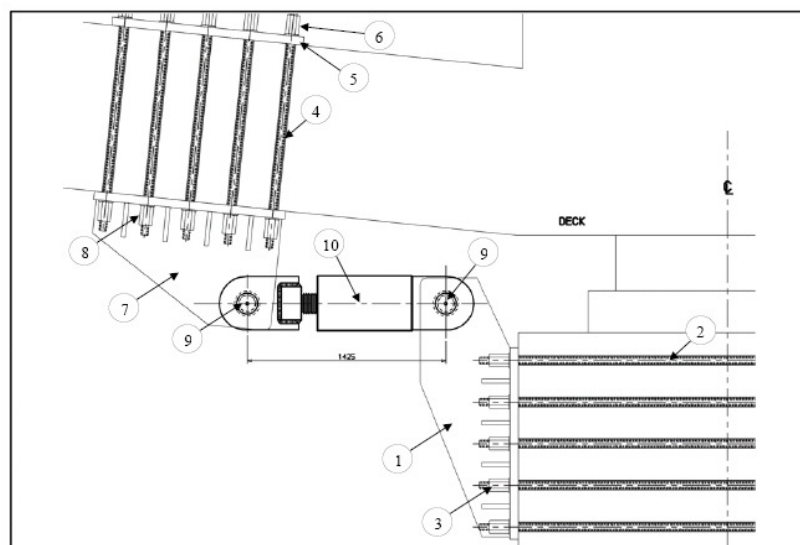
4.3 Proof Tests

The primary purpose of Proof Tests, also known as Quality Control Tests, is to verify the reliability of each STU for this project. To ensure reliability, the Manufacturer will adhere to Section 32.4.3 of AASHTO specifications. Proof Tests will be carried out for each STU for this project. Tests include the following:

- A. Hydrostatic Pressure Test
- B. Slow Movement Test
- C. Fast Movement Test

5. SHOCK TRANSMISSION UNIT INSTALLATION PROCEDURE

If the devices are not installed immediately after their arrival on site, the contractor/client needs to make sure that they are properly stored, i.e. protected against dust, dirtiness, humidity, etc. Installation Procedure of the Shock Transmission Unit (Figure 19) is indicated below:



1. Drill the pier to position the bars with diameter holes of about 60mm, using the anchorage carpentry (pos. 1) for right positions.
2. Make the holes in the deck with a diameter of about 100mm in order to allow possible corrections for the precise placement of the seismic device.
3. Insert the bars (pos.2) in the pier; position the anchorage carpentry (pos.1) and screw the nuts (pos.3) without locking them.
4. Repeat step 3 on the other side of the pier.
5. Insert the bars (pos.4) in the deck; position the anchor plate (pos.5) and screw the nuts (pos.6) without locking them.
6. Position the anchorage carpentry (pos.7) and screw the nuts (pos.8) without locking them.
7. Repeat step 6 on the other side of the pier.
8. Adjust the distance between the anchorage carpentries (pos.1 and 7) using a rigid element 1425mm long and fix it with the pins of the seismic device (pos.9).
9. Repeat step 8 on the other side of the pier.
- 10.Lock the nuts of the deck and the pier (pos. 3,6 and 8).
- 11.Repeat step 10 on the other side of the pier.
- 12.Remove the temporary element (see step 8).
- 13.Insert the seismic device (pos.10) using the turnbuckle to obtain the correct length of the seismic device.
- 14.Insert the pins into the relative holes (pos. 9). Installation complete.



Figure 19 STU Installation Work

6. SHOCK TRANSMISSION UNIT INSPECTION AND MAINTENANCE

Once they are installed the STU devices do not require particular maintenance operations. Because the Hydraulic circuit is completely inside the cylinder there are no parts of the circuit to be externally checked. However, a periodical inspection, which is described below, is recommended.

6.1 Inspection

The inspection process and inspection frequency of the STU after installation is described below:

A. The following items should be checked 6 months after installation and re-checked 1 year after installation”

1. The bolts are tightened properly.
2. Pins are properly placed.
3. Scratches are touched up properly.
4. Any fluid leakages.
5. Any damage to the dust jacket.
6. Holes, if any, are grouted.
7. The area is clean after installation.
8. The labels are available on the STU.
9. Check the stroke length on each STU and temperature.

B. It is recommended to repeat the inspection of the STU devices every two years in order to assure proper device functionality. The following items should be checked:

1. The bolts are tightened properly.
2. Any damage to corrosion protection system.
3. Any fluid leakages.
4. Any damage to the dust jacket.
5. The area is clean without accumulated debris (eg. Bird's nest and droppings).
6. The labels are available on STU.
7. Check the stroke length on each STU to ensure the movement capacity.
8. The pins, spherical bearing surfaces, support bracket and piston rod are adequately lubricated without rust.

6.2 Maintenance

The ALGASISM STUs are maintenance free due to the Hydraulic circuit being completely inside the cylinder as mentioned above. An external inspection of the corrosion protection system on steel parts (eg. Brackets, bolts, cylinder) and restoration, if necessary, is still recommended. The pins, spherical bearing

surfaces, support bracket, and piston rod are adequately lubricated with Lithium-based grease. Any debris accumulated on the STU (eg. Bird droppings, salt, acid) shall be removed by means of brush or high-pressure water to prevent corrosion.

7. CONCLUSION

Shock Transmission Units are widely used in railway bridges within Taiwan and abroad as well as in bridge seismic retrofit projects abroad. They are seldom used in freeway bridges in Taiwan. However, STUs were used in the flyover ramps of the Puyan Interchange (located at STA.207K+600), which is part of the National Freeway (sections open to traffic) Bridge Seismic Retrofit Project (Phase 1). This was because there were four flyover ramps that crossed the Zhongshan Freeway and space was very limited. The engineers did not want the seismic retrofitting work to impede traffic on the Zhongshan freeway, which would have increased social costs. The STUs were installed on the four flyover ramps and have proven to be very effective. The design and implementation process of the STUs for this project, besides advancing bridge seismic retrofitting expertise within the country, can also serve as a reference for future bridge seismic retrofit projects, leading to more reasonably-designed, economical, and safer seismic retrofit designs in Taiwan in the future.

REFERENCES

1. AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTION OFFICIALS , “AASHTO LRFD Bridge Construction Specifications” , 2002.
2. Nicos Makris and Jian Zhang “Structural Characterization and Seismic Response Analysis of a Highway Overcrossing Equipped with Elastomeric Bearings and Fluid Dampers : A Case study” , Nov. 2002.
3. M.C.Constantinou , A.S.Whittaker , Y.Kalpakidis , D.M.Fenz and G.P.Warn , “Performance of Seismic Isolation Hardware under Service and Seismic Loading” , Technical Report MCEER-07-0012 , Aug.2007.
4. Alga S.P.A. , “Antiseismic Devices Type STU 3500/150 Report of the Prototype Tests” , Jul.2008
5. Alga S.P.A. , “Antiseismic Devices Type STU 3500/150 Test Validation Report” , Sep.2008
6. Ta Chen Construction and Engineering Corp. \ Alga S.P.A. “National Freeway Bridge Seismic Retrofit Project (Phase 1) Section M15C STU Design Calculations \ Construction Drawings \ Installation Procedure Manual \ Installation Documents and Qualified Personnel” , Mar.2008
7. Alga S.P.A. , “Antiseismic Devices Type STU 3500/150 Product Maintenance and Repair Manual” , Oct.2008.
8. Ministry of Transportation and Coummunications National Freeway Bureau , “Feasibility Study of National Freeway (sections open to traffic) Bridge Seismic Assessment and Retrofitting” , Mar.2004.
9. Ministry of Transportation and Coummunications National Freeway Bureau , “National Freeway (sections open to traffic) Bridge Seismic Retrofit Project (Phase 1) Detailed Design Report” , Oct.2007.