FAULT-RELATED DAMAGES AND SEISMIC BRIDGE DESIGN; APPLICATION FOR 1999 JIJI EARTHQUAKE IN TAIWAN

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It will be necessary the discussion for the bridge design criteria considering active fault at no distant date. I presume the abutment behavior and pier behavior as active fault occurred between bridge span while I compare the seat type and integral. I apply the concept for the reason of falling bridges on the Jiji earthquake.

Key words*:* *Seismic bridge design, Vertical Bump, Fault, Integral bridges, Seat type abutment*

1. INTRODUCTION

Seismic bridge design used to be considered by static force or dynamic force concerning acceleration coefficient for the site. 1999 JiJi Earthquake in Taiwan was the damage to structures, especially a lot of bridges, inflicted directly by active fault. This issue must be based on a quite different design criteria from those for ordinary seismic bridge design in which ground acceleration and velocities are critical factor. I am aiming at fault-induced bump resulting ground ruptures, which shows the displacement of one-way, not alternation and caused tilted substructures. I assumed that the influence of shaking the bridges was neglected at fault-induced bump area, except rotation vibation. I begin to consider basically the behavior of vertical bump for abutment and pier and horizontal displacement. Next I apply it on JiJi Earthquake and suggest the measure.

2. ABUTMENT BEHAVIOR OF VERTICAL BAMP BY FOUNDATION ROCK

Simple beam bridges of seat type on the rock can be tolerated by fault induced vertical bamp. Seat type abutment can be constructed on the spread footings founded into rock, for it is easy to rotate on the bearing. Figure 1 shows the behavior of seat type abutment on the rock when fault occurred between both of abutments. “L” means span length and “X” means vertical displacement by fault. However it is clear from Figure 2 that integral abutments should not be constructed on spread footings founded or keyed into rock, for causing of severe cracks. It is shown on AASHTO Standard Specifications for Highway Bridges 17th Edition 2002. Figure 2 shows the behavior of integral abutment on the rock.

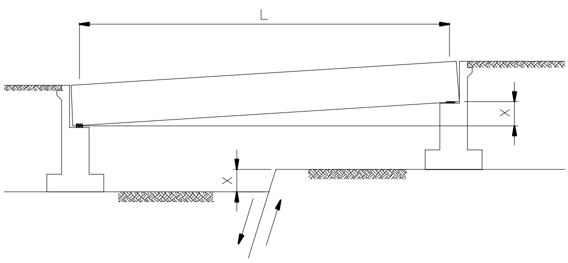

Figure 1. Behavior of seat type abutment on the rock

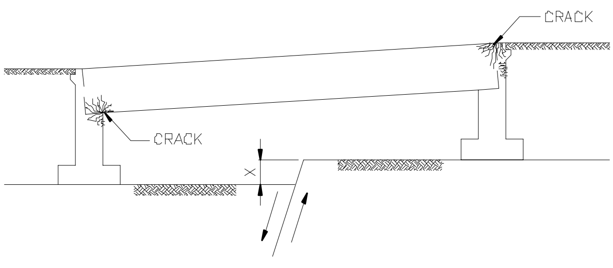

Figure 2. Behavior of Integral abutment on the rock

3. ABUTMENT BEHAVIOR OF VERTICAL BAMP BY FOUNDATION SOIL

The question which we consider here is whether is in compressible soil layer above the fault of rock or in rock about foundation. Jonathan[1] shows that it is Differential Settlement. I should point out that pier and abutment near fault were tilt after earthquake. I presume that transition of displacement make the substructure to be tilt, which displacement were non-uniform and depend on soil property, layer depth "Y" and so on. It is possible to fall the bridge by excess of fault-related displacement. Figure 3 shows the behavior of seat type abutment on the compressible soil layer. It is clear that long span bridges are better than short span bridges, for rotation angle is smaller.

Integral abutment has many cracks but do not fall by excess of fault-related displacement. The reason is to be flexible structure composed by rigid substructure and pile foundation. From the standpoint of avoid the falling bridge, i.e. failure mode to come apart of superstructure and substructure, Integral bridges will be fit for nearness of fault-related damages. Figure 4 shows the behavior of integral abutment (frame abutment integral bridges) on the compressible soil layer.

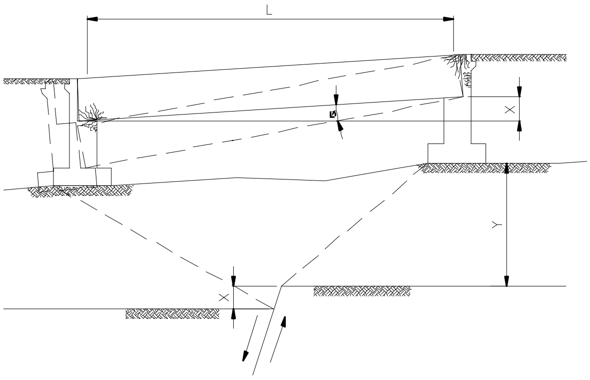

Figure 3. Behavior of seat type abutment on the soil

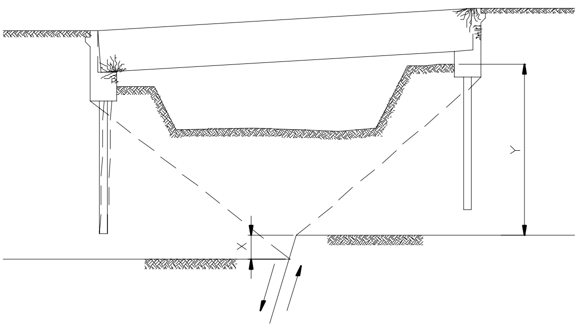

Figure 4. Behavior of integral abutment on the soil

4. PIER BEHAVIOR OF VERTICAL BAMP BY FOUNDATION SOIL

This was the state of affairs in a lot of falling bridges supported by pier after fault-related damages. Note that pier is more rotational than abutment. It is no problem to set on the rock. Figure 5 shows the behavior of seat type pier in the rock. However it caused a bridge girder falling from seat of pier. Because that both of pier is apt to lean on the soil during earthquake.

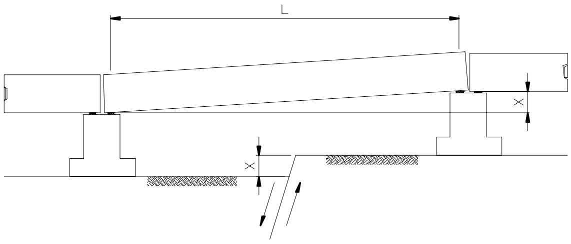

Figure 5. Behavior of seat type pier on the rock

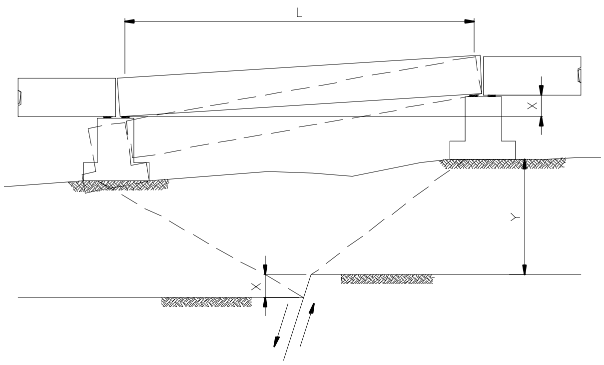

Figure 6. Behavior of seat type pier on the soil

I suggest that no tilting and keeping the stability of substructure is useful for the measure against the vertical bamp of fault, which needs the piles and the connection with superstructure around the area of transition for fault-related damages. In my view, it is one of most desirable bridges that we design the integral abutment and pile foundation for fault. Because that the failure mode is hard to fall the girder from the substructure. Many cracks and minor failure shall be perhaps inevitable.

5. BRIDGE BEHAVIOR OF HORIZONTAL DISPLACEMENT

The behavior of horizontal displacement has no concern with foundation for rock and soil. Equation of “L” and “b” shows as follows.

$$1/2*L \cong \frac{b}{\tan\Phi} \qquad (1)$$

“L” means span length, “b” does right-angled displacement and “ Φ ” does rotational angle. Equation (1) means that short span bridge is apt to fall the girder. Equation of “B” and “a” shows as follows.

$$1/2*B \cong \frac{a}{\tan\Phi} \qquad (2)$$

“B” means bridge width, “a” does displacement. Equation (2) means that wide width bridge is apt to fall the girder.

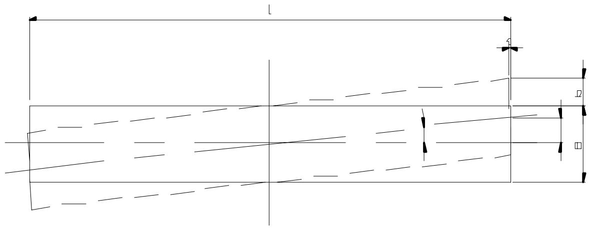

Figure 7. Behavior of horizontal displacement for bridge plan

Note that horizontal displacement also causes the pier and abutment leaning during earthquake. And one of horizontal displacement on the rock may cause a few of horizontal displacement on the surface of soil or underground of soil. Earthquake causes surface fault rapture and underground fault rapture. I suppose that a few of horizontal displacement on the surface of soil or underground of soil is the reason of tilting substructures. That is that horizontal displacement of fault causes the tilting substructure including rotation and the rotation of superstructure. The compound of those sometimes makes a bridge falling.

Regarding to the measure for horizontal displacement of fault, my consideration is that no tilting and keeping the stability of substructure is useful for the measure against the horizontal displacement of fault, which needs the piles and the connection with superstructure around the area of transition for fault-related damages. In my view, it is one of most desirable bridges that we design the integral abutment and pile foundation for fault. The piles should be selected by multi-piles, not single pile like a caisson. Because the foundation is difficult to lean and then the failure mode is hard to fall the girder from the substructure.

Another measurement is to avoid the adoption of wide width bridges or to adopt the long span bridge, which will reduce the influence of fault-related damages. However this method has the defects of possibility for falling girder of bridges.

6. APPLICATION ON JIJI EARTHQUAKE

Kawashima[2] explained the damages of bridges for Jiji earthquake as follows. The Chi-chi earthquake (Mw=7.6), September 21, 1999 in Taiwan, it was apparent that is addition to the near field ground motions, a tectonic fault dislocation was a major threat a transportation facilities, especially bridges.

Chen[3] explained the damages of Pinlinchi Bridge, which includes the displacement of piers and ground by fault movement and piles damages. The foundations were piles and spread footing. It shows the tilting of piles.

I suppose that horizontal displacement causes the pier and abutment leaning during earthquake. And one of horizontal displacement on the rock may cause a few of horizontal displacement on the surface of soil or underground of soil. Earthquake causes surface fault rapture and underground fault rapture. A few of horizontal displacement on the surface of soil or underground of soil is the reason of tilting substructures. Horizontal displacement of fault causes the tilting substructure including rotation and the rotation of superstructure. The compound of those sometimes makes a bridge falling. Figure 8 shows the behavior of viaduct for spread footing and it means the mechanism of falling girder.

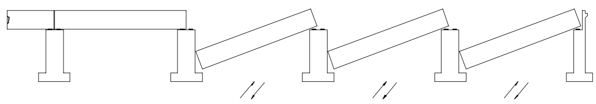

Figure 8. Behavior of viaduct in Taiwan

Regarding to the measure for horizontal displacement of fault, my consideration is that no tilting, no tortuosity and keeping the stability of substructure is useful for the measure against the horizontal displacement of fault, which needs the spread footing easy sliding on the soil and the connection with superstructure around the area of transition for fault-related damages.

In my view, it is one of most desirable bridges that we design the bankseat integral abutment for fault. The spread footing should be able to slide by fault. Because the foundation is difficult to lean and twist of piers, then the failure mode is hard to fall the girder from the substructure. Figure 9 shows the Behavior of bankseat integral bridges.

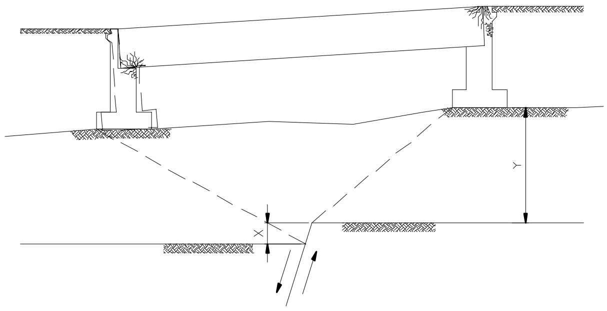

Figure 9. Behavior of bankseat integral bridges

7. CONCLUSIONS

The measure of infliction directly by active fault must be based on a quite different design criteria from those for ordinary seismic bridge design in which ground acceleration and velocities are critical factor. I suggest to concentrate the displacement of one-way, not alternation and caused tilted substructures.

Seat type abutment is tolerable with fault-related damages about vertical displacement on the rock, however it will be possible to fall the girder from the substructure on the soil. Integral abutment is not suitable on the rock but it may be tolerable on the soil except many cracks and minor damages. The reason is to be flexible structure composed by rigid substructure and pile foundation. The damages of seat type pier are more serious than seat type abutment, for the substructure is apt to be tilt. It is useful for the vertical displacement of fault to adopt the long span bridges on the fault and to keep the stability of substructure, i.e. to adopt the frame abutment integral bridges.

Concerning horizontal displacement of fault, seat type abutment shall be felt down by fault. It is useful for the horizontal displacement of fault to adopt the long span bridges, narrow width bridges and the strong connection of substructure and superstructure. Because the foundation is difficult to lean and then the failure mode is hard to fall the girder from the substructure.

We feared the displacement of temperature & shrinkage and thermal force of them, so constructed many joint at girder end. However our priority of bridge design is to be tolerable for active fault-related damages.

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