COLLAPSE OF LUAN RIVER BRIDGE DURING TANGSHAN EARTHQUAKE — A CASE-HISTORY STUDY

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INTRODUCTION

A number of superstructures of 18 bridges fell down during the Tangshan EQ in 1976. Owing to the collapse of beam-spans, traffic was held up and it caused much difficulty to the rescuing work after the quake.

Luan River bridge in Luan County in the area of intensity IX lay to the east of Tangshan city for about 50 km. It was a simply supported R. C. bridge of 35 spans with span length 22.2^m. steel plate supports were used. Stone piers were 8.8^m in height. Pile foundations were $21-27^m$ in depth. The river bed was composed of sand and gravel.

The superstructures of the 2^{nd} to 24^{th} span from west collapsed during the earthquake, the west ends of the beams fell to the river, but the east ends moved distinctly on the piers eastward with a max. value of 0.5^m. The supports were inclined or overturned to the east. The other 11 spans in the east also moved eastward and touched to each other, while the last span to the chest wall of the abutment. In the collapsed spans 12 piers were broken to the east, and the others inclined eastward about 3%. Span length was not changed distinctly, the total length (distance between the two abutments) was decreased not more than 0.5^m.

MECHANISM

Field investigations indicated that the foundation and the bank slope were stable, no liquefaction track was found. Although some piers were broken, but their caps fell onto the decks of the collapsed span. It indicated that the piers did not break until the beams fell down at first. Because the beam spans moved towards a same direction, and it was 0.5^m wide from the support to the boundary of pier top, there must be a relative displacement of at least 0.5^m before the collapse. Such a large displacement could not be explained as the nonlinearity of materials or the time difference of earthquake motion.

Owing to the large number of spans, and there was an interval of $3-5^{cm}$ between every two neighbor spans, by adding up these intervals the total length could amount to a value which is big enough for collapse. Then we infer that the large displacement of the beam on the pier top might be caused by the accumulation effect of several slides. This accumulation effect included not only that of the two earthquakes (main quake $M = 7.8$ and the main aftershock $M = 7.1$ in the same day, the collapse happened during the last quake), but also that of the several slides during one quake. The later

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could essentially be the cause of collapse.

Consequently, we imagine the process of collapse as follows: At the beginning of the earthquake the beam vibrated together with the pier. When ground motion intensified and exceeded the critical value which the supports were able to bear, the velocity of the beam could not catch up with the pier, the beams jumped down (earthquake vertical component might play a role probably) from the supports, and the supports were overturned. A separate state between the beam and the pier began. Synchronism would not return to normal until the motion of the pier decreased and velocities of the both resumed to be equal. But the relative displacement found during the separate state would retain. Such displacements happened repeatedly, and would add up.

ANALYSIS

In this paper, an analysis is based on Newmark's (1965) idea about soil slope stability. The critical friction coefficient of the steel plate supports is supposed as $k_r = 0.15$. We consider a simple harmonic vibration as shown in fig. 1 (with period T_1, acceleration amplitude $K_m g$, $K_m > K_r$). an overload pulse ($t_1 < t < t_2$) would cause a relative displacement as approximately

$$S_1 = \frac{1}{\pi} (K_m - K_r) g \cdot (t_2 - t_1)^2$$

Although the accel. of the pier top decreased to K_r again when $t = t_2$, but the beam and the pier still didn't return to equivalent motion. It is because they had got different velocities, of which the difference was the area of shadowy part of fig 1, i.e. $\frac{2}{\pi} (K_m - K_r) g (t_2 - t_1)$. Till $t = t_3$ while the velocities became equal, the both returned to coincidence again. During the time interval $t_2 < t < t_3$ a relative displacement was approximately

$$S_2 = \frac{1}{2} \left(\frac{2}{\pi} K_m g \right) (t_3 - t_2)^2$$

$$= \frac{1}{\pi} \left(\frac{K_m - K_r}{K_m} \right) (K_m - K_r) g (t_2 - t_1)^2$$

Consequently, an overload pulse $(K_m - K_r) (t_2 - t_1)$ would cause a total relative displacement

$$S = S_1 + S_2 = \left(1 + \frac{K_m - K_r}{K_m} \right) S_1$$

It is important that the beam and the pier still retain relative motion during $t = t_2 - t_3$, and the opposite pulse ($t > \frac{T}{2}$ in fig.1) after the former positive pulse must be mainly missed. Hence, for a simple harmonic process the odd pulses with same direction would be accumulated, while the even pulses with opposite direction couldn't take place, and it led to a motion of several slides with same direction. Although it could be more complex for an earthquake, but the above mentioned character of relative motion still would be a main reason of collapse towards a same direction.

However, it must be noted that some structural factors might also be reasons for the mechanism of accumulation, such as:

1. After the beam spans jumped down from the support, the support plates can hinder them from moving conversely.
2. The abutment will stop a backward slide.

COLLAPSE OF THE LUAN RIVER BRIDGE

The longitudinal fundamental frequencies of the Luan River bridge in Luan County measured (in 1977 while it was being rebuilt) by the IEM were

$$f_1 = 4 \text{ Hz} \quad \text{(before the erection of beams)}$$

$$f_1' = 1.5 \text{ Hz} \quad \text{(after the erection of beams)}$$

and the longitudinal stiffness of a pier was evaluated as $K = 3170$ t/m. The weight was assumed 300^t for a single span and 200^t for a pier.

Take the ground motion record of an aftershock of the Tangshan earthquake received on a bed rock on an end of the Luan river bridge in Qian-an County (about 30 Km upstream from Luan County) as an input as shown in fig. 2 (a). The soil layer of the river bed was assumed as 18^m in depth. For the soil $G = 5000$ t/m , $\nu = 0.4$, $\gamma = 2$ t/m³ , $\mu = 0.07$. The EQ response of the river bed surface was evaluated as shown in fig. 2 (b). Then the acceleration response of the pier top was defined as in fig. 2 (c). Some relative displacements were obtained as follows:

No.	1	2	3	4	5	6	7	8
$(K_m - K_r)g$ (m/s²)	+0.82	-2.74	+3.94	-4.23	+3.28	-1.65	+2.60	-2.48
$t_2 - t_1$ (sec)	0.15	0.21	0.24	0.24	0.26	0.27	0.25	0.22
S_1 (m)	0.006		0.072		0.071		0.052	
S (m)	0.008		0.124		0.12		0.085	

summing up all the positive values, a total relative displacement could amount to 33.7 cm.

DISCUSSION

1. Accumulation effect of several slides of beams on the pier top during an earthquake could be a main reason of collapse of multi-span simply supported bridge. Consequently, some aseismic measures to avoid an accident like the Luan River bridge might be simple and possible.
2. The fallen span ends of the Luan River Bridge in Luan County were all the ends near the epicenter of the Tangshan earthquake, and so was the Luan River Bridge in Qian-an County. However, it is unknown whether these phenomena are occasionary or certain (i.e. relating to the position of the epicenter).

The collapsed Luan River Bridge

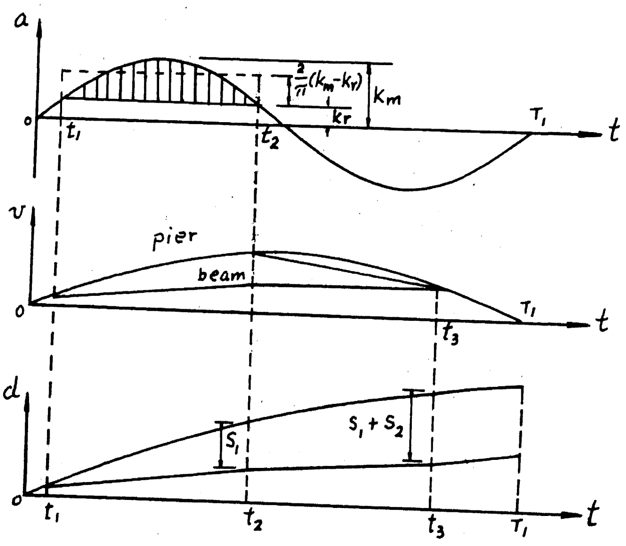

Fig. 1. Slide of beams on pier

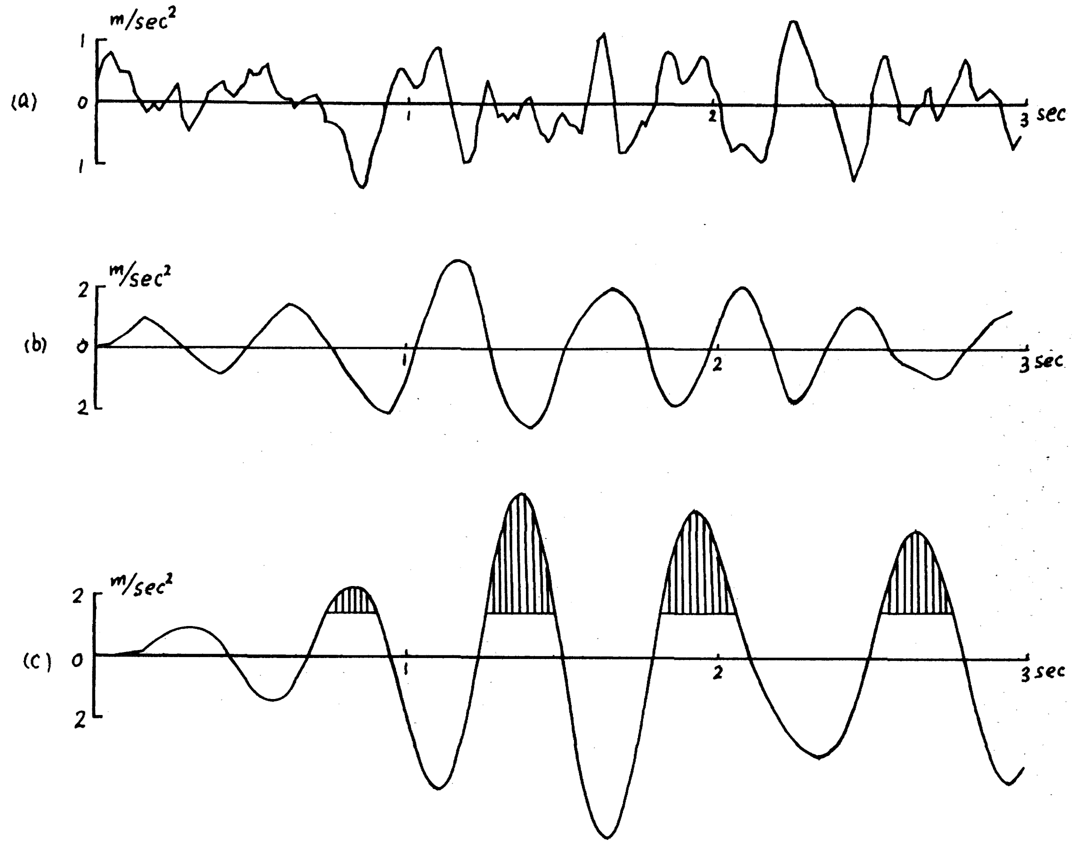

Fig. 2. Response of Luan River Bridge
(a) base input (b) surface response of 18^{m} layer
(c) response of pier top