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The Inclination of Bridge Pier Due to Neighboring Embankment Construction and Its Rectification Technique

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Abstract: In case of highway road construction often beneath existing overpass project, the filling of neighboring embankment may cause lateral displacement of bridge piers, which seriously threaten the safety of bridge. One case history, for inclination disease of overpass bridge piers in soft soil area, was presented. Aiming at the deformation of piers caused by the neighboring embankment construction, the displacement feature of bridge bearings were tracked and measured by site monitoring, and the damaged position of piles were clarified with low strain dynamic test. For these geological traits, the reasons of the inclination were analyzed. And the rectification method of applying surcharge load for smaller deviation (≤50mm) and the rectification method of pushing combined traction for serious deviation (>50mm) were respectively put forward on the basis of the lateral displacement statistics of bearings and the analytical standard set by Bozozuk. Site observation indicates these rectification methods can achieve the desired results.

Introduction

With the rapid development of the highway construction, interchanges which connect all the roads have increased. In case of highway road construction often beneath some existing overpass bridges, the filling of embankment may cause lateral displacement of bridge piers, especially in soft soil area. As application of the embankment load to the surface of a soft clay layer, it may results in immediate undrained lateral soil movement away from this surcharge load [1,2,3]. If a structure is in the region of deformation, for example buildings pile foundation, soil will move laterally past the piles causing so called, passive lateral pressure to be applied to the piles. This pile loading can create additional bending moments and deflections, and may lead to superstructure distress or failure. But in many cases piles are not designed to sustain lateral soil deformation, and indeed, several instances of structural damage to piles have been reported in literatures, for example, Hagerty and Peck(1971) and Finno et al,(1991)[4,5,6].

To help shed light on the understanding of structure performance which affected by neighboring surcharge load, a case history in Lianyungang City, Jiangsu Province, China has been carried out. This paper describes the inclination of several interchange bridge piers caused by neighboring embankment construction, and analysis the reasons of deviation accident and its damaged condition. In the end, two rectification methods are provided. For the smaller (≤50mm) deviation piers, applying surcharge load treatment is employed, and for serious (>50mm) deviation piers, pushing combined traction treatment is carry out. Site observation indicates these rectification methods can achieve the desired results, so it can be applied to other similar projects.

Engineering Profile

XG and SD are two interchanges of a highway road in Lianyungang City, Jiangsu Province, China, and they are all used the clover leaf combined directional ramp type, just as shown in Fig.1. In the XG interchange, there are three flyover bridges: main line road flyover XG road bridge (MX for short), B ramp flyover XG road bridge (B1 for short) and main line road flyover B ramp bridge (B2 for short). And the XG road beneath through main line road between 26# and 28#piers, beneath through B ramp between 5# and 7# piers, respectively. Meanwhile, B ramp beneath through main line road between

34# and 35# piers. At the same form, SD interchange also has three flyover bridges: main line road flyover SD road bridge (MS for short), A ramp flyover SD road bridge (A1 for short) and main line road flyover A ramp bridge (A2 for short). And the SD road beneath through main line road between 8# and 10#piers, the SD road beneath through A ramp between 4# and 6# piers, A ramp beneath through main line road between 16# and 17# piers, respectively. The relative position of each flyover bridge and beneath road is shown in Table.1 in details.

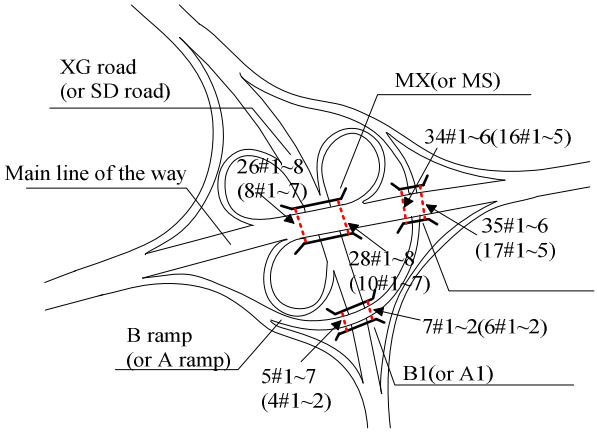


Fig.1 Plan of interchanges

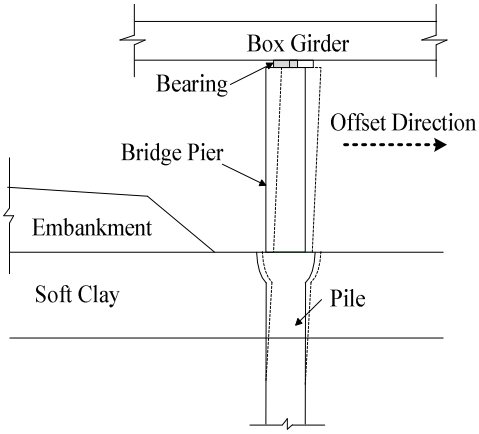


Fig.2 Inclination of bridge pier

Table.1 Relative position of flyover bridges and beneath roads

Bridges		Piers No.	Piers Position	Horizontal Distance/m
XG interchange	MX	26#1~8	Left of XG road	3.50
		28#1~8	Right of XG road	2.37~4.20
	B1	5#1~2	Left of XG road	10.10
		7#1~2	Right of XG road	8.50~9.30
	B2	34#1~6	Left of B ramp	4.60~5.90
		35#1~6	Right of B ramp	7.00~8.20
SD interchange	MS	8#1~7	Left of SD road	4.30
		10#1~7	Right of SD road	3.30~4.80
	A1	4#1~2	Left of SD road	9.70
		6#1~2	Right of SD road	8.70~8.90
	A2	16#1~5	Left of A ramp	3.90~6.30
		17#1~5	Right of A ramp	7.70~9.50

The six bridges are all using column piers in which pile diameter is 1.6m and column diameter is 1.2m. For convenient construction, the filling of crossed embankment began carry out until these bridges pile foundation construction complete. When the filling is complete, bridge piers are discovered occur displacement in the direction of away from neighboring embankment (Fig.2), especially the 26# and 28# piers of MX bridge and the 8# and 10# piers of MS bridge. The offset displacement of each pier is shown in Table.2.

Table.2 Offset displacement of piers

Bridges		Piers No.	Height of embankment /m	Foundation treatment method	Offset displacement/mm	
					Top	Footing
XG interchange	MX	26#1~8	1.1	Preloading	32~66	15~46
		28#1~8	2.3	Preloading	102~133	71~106
	B1	5#1~2	1.2	Preloading	5~10	-
		7#1~2	2.0	Preloading	1~3	-
	B2	34#1~6	2.6	Cement mixing pile	6~49	-
		35#1~6	2.5	Cement mixing pile	0~13	-
SD interchange	MS	8#1~7	1.5	Preloading	39~108	19~73
		10#1~7	1.5	Preloading	23~67	16~56
	A1	4#1~2	1.9	Preloading	48~50	-
		6#1~2	1.9	Preloading	2~24	-
	A2	16#1~5	2.2	Cement mixing pile	3~17	-
		17#1~5	2.8	Cement mixing pile	5~36	-

Inclination Analysis

As shown in Table 2, the top and footing offset displacement of all the piers in the six overfly bridges are monitoring. It can be seen, 28#piers top bearing offset displacement of MX bridge most serious (>100mm), the maximum bearing lateral displacement is about 133mm, and appeared in the 7th pier. In addition, the top bearings offset of 26# (MX bridge), 8# and 10# (SD bridge) are about 33~78mm. But in the other four overfly bridges, the inclination of piers are very small, only several piers displacements >25mm. Moreover, the influence of the distance from embankment and the foundation treatment methods are also shown in Table 1 and Table 2. The top bearings offset displacements are smaller as the piers farer away from neighboring embankment, for example, the inclination of 7#piers (8.5~9.3m away from neighboring embankment) of B1 bridge are smaller than 28#piers (2.37~4.20m) of MX bridge as the height of the two embankment are about the same (2.0m and 2.3m respectively). And compared to the case of there is no foundation treatment or preloading treatment, the inclination of piers are very smaller even though the height of neighboring embankment is relatively higher for the case of cement mixing pile foundation treatment used, as in Table 2.

Aiming at analysis the reasons of the inclination of piers, the geological characteristic of the project is analyzed at the first. The inclination is only occurred at the junctions of the roads which located in Lianyungang City. Thick muddy soil lay on upper part of the subgrade, the physical and mechanical indexes of every layer are shown in Table 3. It can be seen, the ① 2 muddy soil as is called marine deposit soil is very soft, and its thickness is about 15.5~22.0m. Its moisture content, pore-ratio and compressibility coefficient are about 69.2%, 1.946 and 1.88MPa^{-1}, respectively. So during the construction of neighboring embankment, immediate undrained lateral deformation away from the embankment load may be occurred in this soil layer, due to its high pore-ratio, lower strength and high compression [7]. Accompanying extrusion of this soil, addition lateral deflections and bending moments may be occurred in the nearby piles of the overfly bridges foundation. And then, the piles deflection and passive lateral pressure could lead to the inclination or damage of the bridge piers. In addition, the lateral deflections of the piles will increase with the time going on due to the consolidation of muddy soils. Consquently, the lateral displacement of the thick muddy soil under neighboring embankment is the primary cause of the inclination of the bridge piers.

Table.3 Physical and mechanical properties of soil strata

Soil layer	Thickness h/m	w /%	γ /kNm^{-3}	e	I_P	I_L	φ /°	c /kPa	E_s /MPa	q_c /MPa	f_s /kPa
①1 Clay	1.7~2.5	40.1	1.79	1.143	25.2	0.57	7.2	22.9	3.43	0.30	25.2
①2 Muddy	15.5~22.0	69.2	1.57	1.946	31.9	1.23	2.0	8.7	1.52	0.34	9.7
①2a Clay	0.0~10.8	35.8	1.87	0.989	20.5	0.67	5.7	28.2	4.10		
③1 Clay	1.5~14.0	29.2	1.92	0.842	15.1	0.37	12.9	39.4	5.82	1.14	38.0
③1c Sand	0.8~4.2	18.9	2.04	0.582			20.2	30.1	8.04		
④1 Clay	1.0~18.5	23.9	1.99	0.703	15.1	0.22	17.8	43.2	5.40		
④1c Sand	0.0~4.5	17.1	2.02	0.581			20.1	29.0	5.84		
⑤1 Clay	--	20.4	2.00	0.659	14.2	0.20	19.8	45.2	7.97		
⑤1c Sand	--	15.6	2.03	0.545			26.0	18.2	10.09		

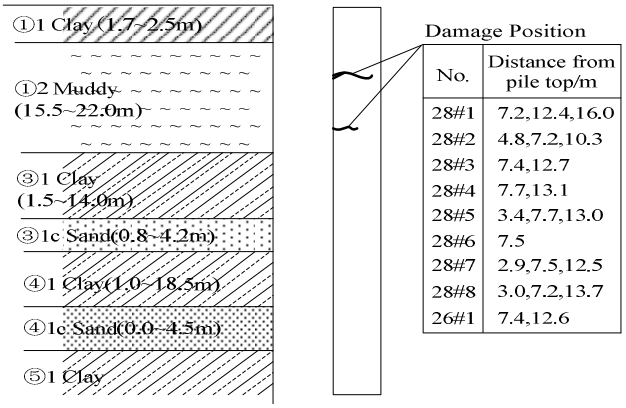


Fig.3 Results of low strain dynamic test

Moreover, low strain dynamic test is conducted in 9 piles of 26#, 28#piers in order to get the damage position of the piles. Test results are shown in Fig.3. It can be seen, the 9 tested piles are all no broken, but there are some minor damage on the piles just as slight cracks. The cracks basically located at 7.0~7.5m, 12.0~13.5m away from the pile top where almost within the muddy soil layer. This phenomenon shows that the piles are subjected horizontal thrust, and further evidence that the primary cause of the inclination is lateral deformation of muddy soil.

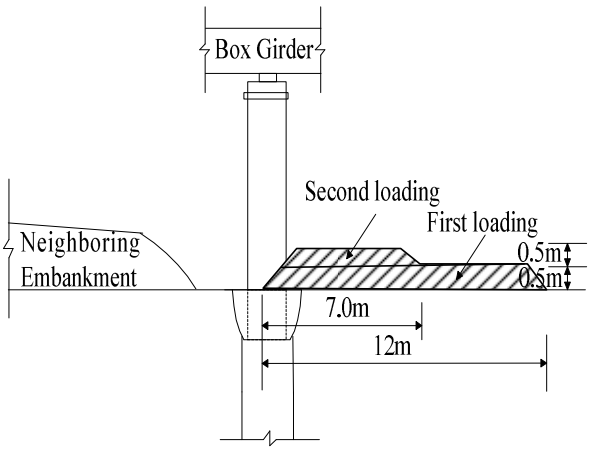
Rectification technique

Based on the inclination monitoring and pile foundation quality testing, and refer to the bridge damage assessment standard (as shown in Table4) by Bozozuk[8], two rectification methods of the inclination piers are carried out: applying surcharge load method and pushing combined traction treatment, just as shown in Fig.3~Fig.4.

Table 4 Damage assessment of piers (by Bozozuk)

I		II		III	
S_v/mm	S_h/mm	S_v /mm	S_h /mm	S_v /mm	S_h /mm
≤50	<25	50~100	25~50	>100	>50
Could withstanding the inclination		Upper structure damaged but not influence use		Upper structure severely damaged	

As the primary cause of the inclination of the bridge piers is the lateral displacement of the thick muddy soil due to the embankment surcharge load, the method of applying surcharge load on the other side of piers is used for the smaller deviation (offset displacement of pier top, S_h≤50mm) piers on the same mechanism. For the balance of the load on the both sides of piers, it can prevent the inclination further increase. The applying surcharge load is divided into two level in this project, 26#, 34#, 35#, 5#, 7# piers in XG-interchange and 10#, 16#, 17#, 4#, 6# piers in SD-interchange are used this method. Detailed implementation steps as shown in Fig.3.



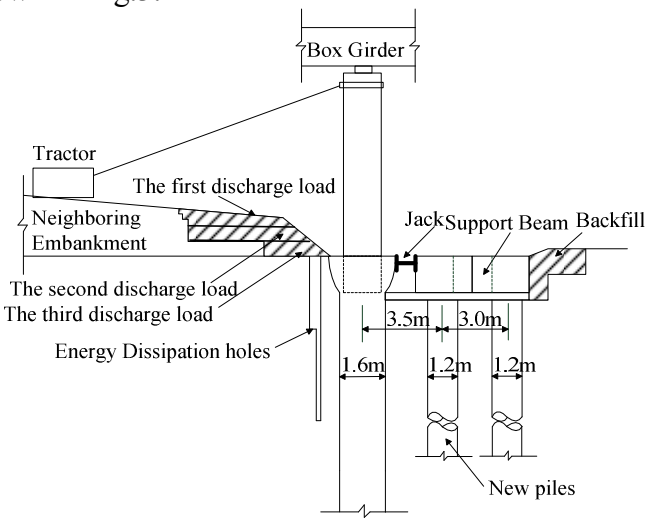


Fig.3 Treatment solution of surcharge load **Fig.4** Treatment solution of pushing method combined traction

As the inclination of the other piers in the two interchanges are very serious (S_h>50mm), the method of pushing combined traction treatment is carried out. 28#piers in XG-interchange and 8#piers in SD-interchange are used this method. Detailed implementation steps as shown in Fig.4.

Fig.5 and Fig.6 present the bearings lateral displacement before and after the rectification conducted. It can be seen, the lateral displacements of the piers are all less than 50mm (some piers even returned the original position) and it have no influence for the upper structure. In addition, the treatment results for pushing combined traction treatment method are better than applying surcharge load method. For example, the lateral displacements of 8 bearings of 28#piers and 7 bearings of 8#piers are reduced about 79.7%~92.1% and 84.7%~100%, respectively. On the contrary, the lateral displacements are reduced about 10.7%~43.7% for the method of applying surcharge load.

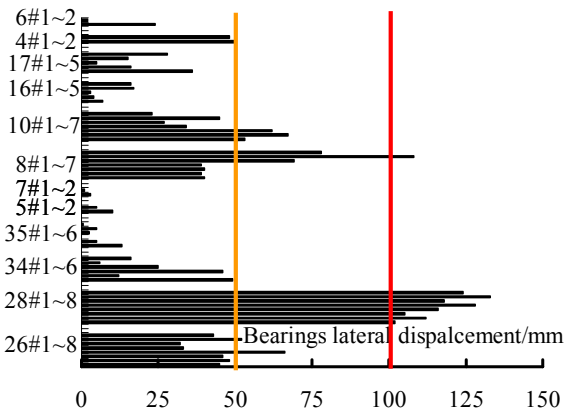


Fig.5 Bearings lateral displacement before rectification

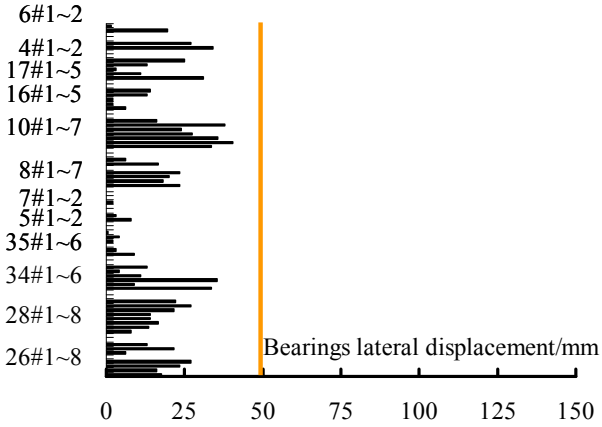


Fig.6 Bearings lateral displacement after rectification

Conclusions

A case history of inclination of bridge piers nearby embankment is presented. The deformation condition of piers and damage feature of piles are analyzed. Following conclusions may be made:

(1) The lateral deformation of muddy soil due to applying neighboring embankment load is the primary cause of the bridge piers inclination in interchanges, and its resulting engineering diseases should be considered.

(2) The height of neighboring embankment, the distance away from neighboring embankment and the foundation treatment method are all influence factors of the bridge piers inclination.

(3) Based on the analysis of the inclination impact, the rectification method of applying surcharge load for smaller deviation (≤50mm) and the rectification method of pushing combined traction for serious deviation (>50mm) are respectively carried out, and the observation indicates these rectification methods can achieve the desired results.

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