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The effect of spring coefficients in the dynamic analysis model of the pile foundation structure in Binh Thuan seas, Vietnam

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Abstract
Now, the field experiments according to the non-destructive test method are developing widely in diagnostics and verification of structural engineering. To research and apply the impact vibration test, one of these non-destructive methods, the construction of the design dynamic analysis model is significant. The paper goes into research on the formulas to determine the dynamic spring coefficients according to Japanese and Vietnamese standards. Then, apply calculations for dynamic analysis models of pile foundations built in the Binh Thuan sea area. The impact vibration test in the field shows the appropriate formula for calculating the coefficient of dynamic springs in Binh Thuan, Vietnam.

Keywords: Spring coefficient, the design dynamic analysis model, impact vibration test.

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INTRODUCE

In some countries with advanced science and technology, the non-destructive method (shock pulse, impact vibration test) use increasingly, especially the impact vibration method, to assess the technical operation state of the supper structure and the pier structure [1, 2]. In Japan, the impact vibration test (IVT) specify in structural maintenance [3, 4]. According to this test, the health index of structure k determined by the measured natural frequency and the standard value of natural frequency. Compare and assess the health index of structures κ with evaluation criteria and conclude the inspected construction (apply Japan standards). There are three methods to define the standard value of natural frequency as below:

It's comparative with the natural vibration frequency which measured in the past;

It's comparative with the standard value of natural-vibration frequency (this standard value may specify formulas in Japan standard);

It's comparative with a design value of natural vibration frequency. Otherwise, from natural vibration frequency determined via measurement results, evaluate the soil's pier' hardness, comparative these values with design values.

In Vietnam, the evaluation of the port structure uses the static test method. It must be the horizontal forces that make anchors or berthing of design vessels. It isn't easy to do during the inspection period. So, assessing the general, full condition of the berth structure, the IVT method is a good selection. The ports are operating is entirely to apply IVT with the 3rd method.

To define the index of structure κ follows the 3rd method is very necessary to study a theoretical dynamic analysis model of the structure [5] has shown that the dynamic ground coefficient for different soil types is different, and each has a value greater than 2 (silica sand: 2.8; kaolin clay: 2.4; volcanic ash: 2.3). According to [6], the dynamic ground coefficient equals about 1.55 clay, mud - silt - peat 1.4–1.8 static ground coefficient. According to [7], this value is two times.

The article concentrates on research on dynamic spring coefficients in the theoretical dynamic analysis model. To evaluate some jetties, the IVT in the field shows the appropriate formula for calculating the coefficient of dynamic springs in Binh Thuan, Vietnam (fig. 1). It is assumed that the actual measured natural fre-quency and the natural design natural frequency are the same. In other words, the actual construction of the pile foundation structure is the same as the design calculation.

Figure 1. IVT at Binh Thuan sea

GEOTECHNICAL INVESTIGATE AT BINH THUAN SEA AREA

The typical geotechnical condition at Binh Thuan Sea Area are following in table 1.

The purpose of the standard penetration test (SPT) is to measure a number of standard penetration hits in soil layers, to judge the density of sand or consistency of clay, evaluate the liquefaction of sand, define weathered grades of rock layers, and determine subgrade bearing capacity or strength, deformation indices and spring soil coefficients. During the investigation in the IVT stage in the coal jetty and approach area, a total 435 times of standard penetration tests have been carried out in 5 sub-layers. For statistics, abnormal data have been rejected. For statistical results of standard penetration tests carried out for each soil layer, refer to table 1.

Table 1. Statistical results of SPT

Layer No.	Soil type	Thickness	SPT
(2)	Coarse sand with muck	1.1 ~ 4.2	25
(4)	Medium sand with clay	8.2 ~ 17.8	33 ~ 100
(4a)	Medium sand with clay	4.4 ~ 8.8	12 ~ 39
(4b)	Clay	1.4 ~ 5.3	16 ~ 41
5	Highly weathered granodiorit	3.3 ~ 11.6	51 ~ 100

CASE STUDY

The status of pile foundation

The length of the approach trestle is 135 m in total, including abutment and frame. The profile of it is 18.9 + 18.6 × 4 + 19.6 (m). The width of the approach trestle (the distance between the inner edges of parapets) is 8.0 m. The approach trestle support is located on the foundation of a steel pipe pile, including five piles diameter D1000. The transverse frame supporting the trestle girder placed on the foundation of the steel pipe consists of 2 frames with a diameter of D1000. Details are shown in fig. 2, 3:

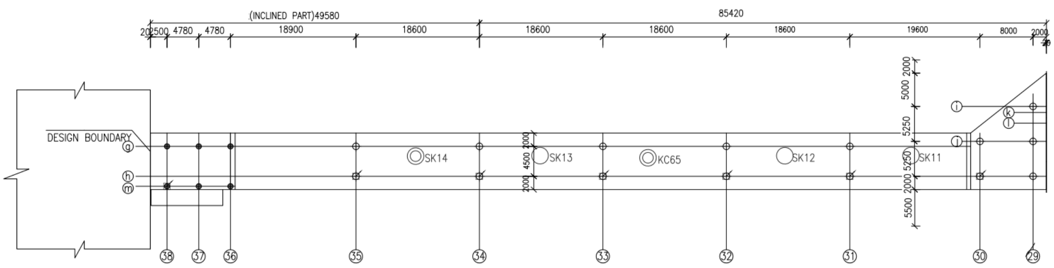

Figure 2. The plan of approach trestle of the jetty

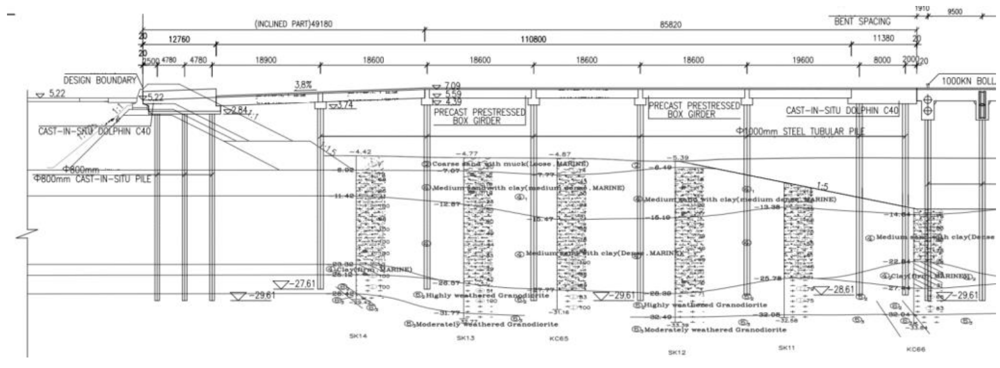

Figure 3. Profile of approach trestle of the jetty

Spring constants

Spring constants are calculated according to TCVN10304-2014 are similar Japanese standards, in which the formula calculates reaction coefficients:

$$C_z = kZ/\gamma_c \quad (1)$$

In which: k is a factor, by kN/m^4, estimated depend on the soil around piles, according to table 2 of this standard; Z is the depth of pile segment in soil, where reaction coefficients are calculated, and it is calculated from the ground with high footing pile foundation and from bottom of footing with low footing pile foundation. γ_c is the coefficient of working condition (with single pile $\gamma_c = 3$).

Calculation the reaction coefficients according to Vietnamese standards depends on the ratio coefficient table (5 types) and the depth of cross-section. The method of checking the table is not accurate because the reaction coefficient k depends only on the soil and some physical parameters of the soil is not reasonable. On the other hand, the scope of the survey is extensive (the same soil, the final value and the initial value are different 1.5–2 times). This standard does not apply to the design of pile foundations on the sea and offshore.

According to Japanese standard, it is easy to determine the reaction coefficients, reaction coefficient of transverse, vertical of pile and pile tip when no pile test result (base coefficient determined based on the relationship between jet and displacement by the equivalent method using geological survey results at the construction site). In addition, the formulas which are used to calculate reaction coefficients have been studied separately for the structure of the port facility and other auxiliary structures in the port, especially the structure of the high footing foundation.

Table 2. Calculation of statics spring constants (Outside diamenter D = 1 m) - Approach Trestle

STT	SPT	$K_x = K_y$ (kN/m^3)	K_z (kN/m^3)	li (m)	$K_x = K_y$ (kN/m)	K_z (kN/m)
1	7	10500	3500	1	10500	10996
2	7	10500	3500	1	10500	10996
3	19	28500	9500	1	28500	29845
4	40	60000	20000	1	60000	62832
5	68	102000	34000	1	102000	106814
6	25	37500	12500	1	37500	39270
7	71	106500	35500	1	106500	111527
8	90	135000	45000	1	135000	141372
9	100	150000	50000	2	300000	314159
10	95	142500	47500	3	427500	447677

In the guideline of dynamic analysis testing, the reaction coefficients of the design dynamic analysis models are triple the initial reaction coefficients.

To define some statics reaction coefficients of Binh Thuan sea shown in table 2.

The research cases of dynamic reaction coef-ficient are assumed as follows:

Case 1: The dy-namic analysis' reaction coefficients as static analysis as;

Case 2: Reaction coefficients of dynamic analysis triple higher than that of static analysis;

Case 3: Reaction coefficients of dynamic analysis double higher than that of static analysis.

The initial reaction coefficients according to the Vietnamese Standard are usually smaller than the Japanese Standard.

Design method of theoretical dynamic analysis model

Numerical models are made by software SAP2000. Dynamic analysis of the structural model according to the eigenvalue method was conducted in SAP 2000.

Material is in accordance with designed documents.

Strength of rebar steel is not less than 400 Mpa, and strength of hoop steel is not less than 240 Mpa.

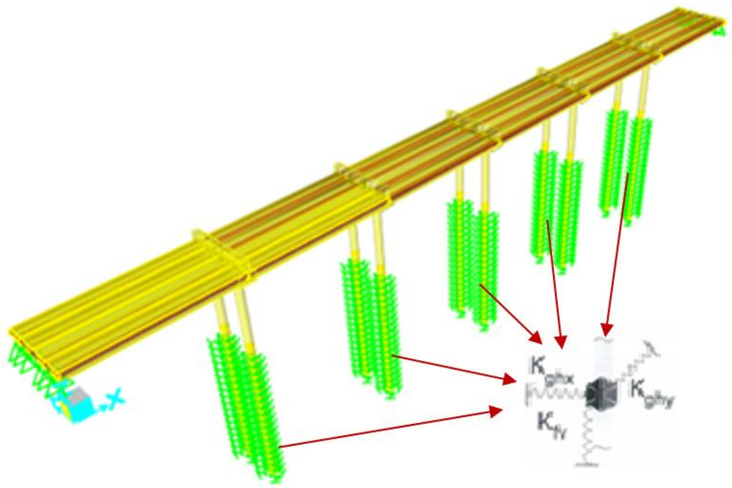

Figure 4. The dynamic spring dynamic in theoretical dynamic analysis model

Table 3. Statistical results of the natural frequency

Case	Mode 1 (axis *x*)	Mode 2 (axis *y*)	Mode 3 (axis *z*)
1	2.3649	6.0734	6.8205
2	2.3787	6.0795	7.0953
3	2.3869	6.0831	7.2630

Spring coefficients are used to connect between soil and piles. The theoretical dynamic analysis model of pile foundation sees in the fig. 4. The natural frequency of the theoretical dynamic analysis model for the cases is listed in table 3.

IVT in the Binh Thuan sea

IVT' pile foundation at site shown in fig. 5, table 4.

The data have collected on 2 directions: transverse, vertical. The below fig. 6, 7 are transversal data.

Figure 5. Establish lateral impact forces

Table 4. Statistical results of the natural frequency from IVT

Items	Transversal frequency		Longitudinal
	Min. (Hz)	Max. (Hz)	Max. (Hz)
Segment of Approach Trestle	2.335	2.808	7.993

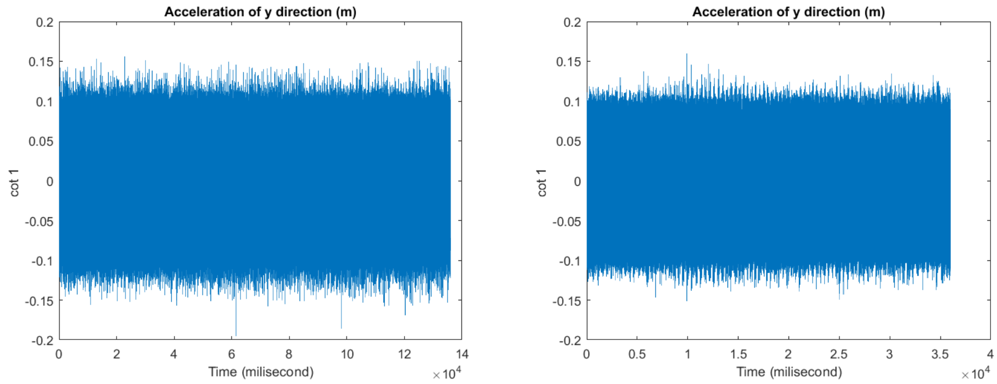

Figure 6. Transverse acceleration (the 1st, 2nd)

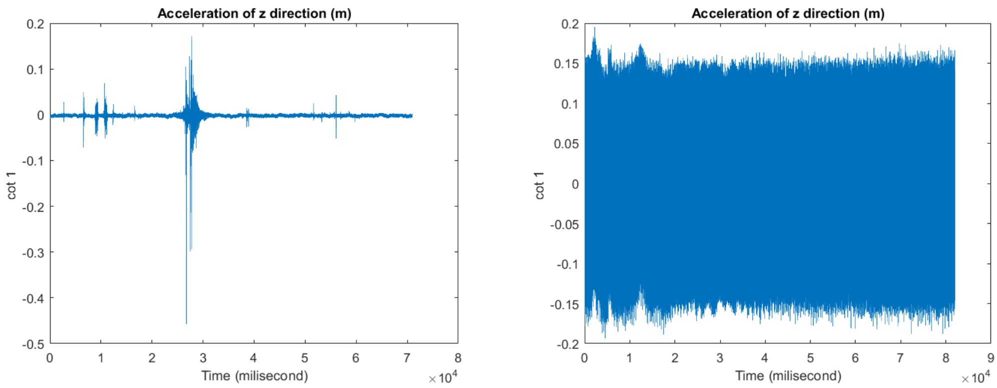

Figure 7. Vertical acceleration (the 2nd)

The measured frequencies obtained in figures. 8–9 (refer to [8]) from IVT experiments as follows:

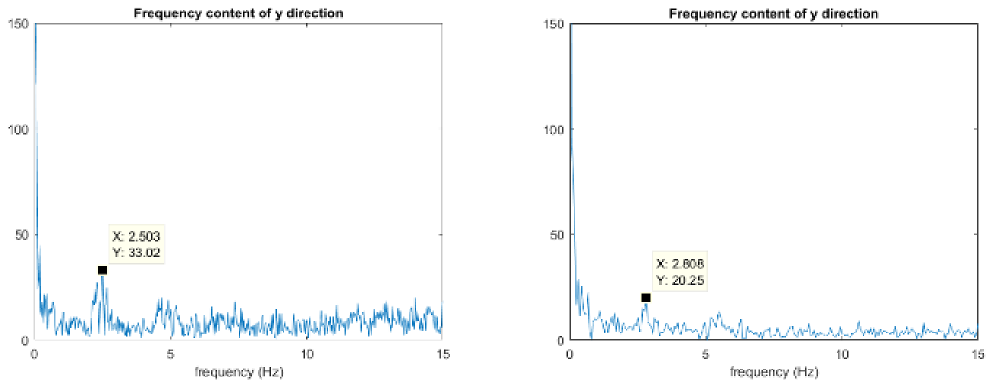

Figure 8. Measured frequency's transversal (the 1st, 2nd)

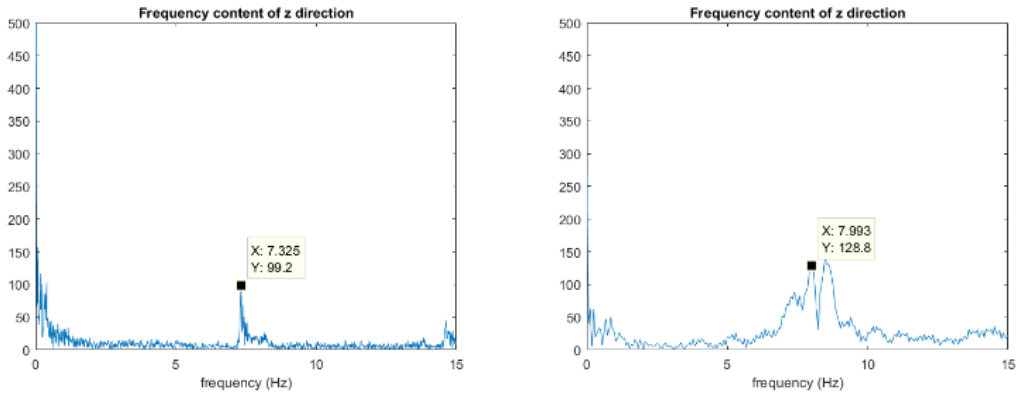

Figure 9. Measured frequency's vertical (the the 1st, 2nd)

Result

According to, index of soundness κ approach S then the structure is entirely healthy. So if the pile structure has just finished the construction, it is correct on initial design then $\kappa \geq 1$. In this situation, the theoretical dynamic analysis model must have a suitable natural frequency. This natural frequency is less than the measured frequency.

The influence of the spring coefficient in the theoretical dynamic analysis model is seen in table 5.

Table 5. Health index

Case	Health index		
	Transversal		Vertical
	Min	Max	
1	0.9873	1.1873	1.1719
2	0.9815	1.1804	1.1265
3	0.9782	1.1763	1.1005

With all three cases, the dynamic analysis model gives consistent results. The model with the dynamic spring coefficient equal to three times the static results for the smallest index's κ will be selected to evaluate the structural engineering condition. This conclusion ensures structural safety.

CONCLUSION

For geology in the Binh Thuan sea area, the spring coefficient's influence in the dynamic analysis model is negligible when taking 2 or 3 times the static base coefficient according to coefficient calculation, according to Japanese standard. Experimental results show that in all 3 cases, the health factor is greater than 1. This conclusion is because the construction works are by the original design and the less compacted soil and gravel geology.

However, if calculating the base coefficient according to Vietnamese standards, there is a significant change.

It is necessary to conduct IVT tests in different regions to determine the base coefficient or spring coefficient used in dynamic analysis.

IVT is conducted simple and quickly for accurate results of the overall technical condition of the structure. IVT can apply widely in the quality inspection of the berth structure. This case recommends calculating the base factor according to the Japanese Port standard (using the SPT index).

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