Research on Vibration Safety Evaluation and Control Standards for Gravity-type quay walls

Mingxing Zhu[1,2,3,*], Yang Zhou[4], Kunpeng Wu[1,2.3] and Zhijun Liu[1,2,3]

[1]CCCC Fourth Harbor Engineering Institute Co., Ltd, Guangzhou 510230, China
[2]Key Laboratory of Environment and Safety Technology of Transportation Infrastructure Engineering, CCCC, Guangzhou 510230, China
[3]Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai 519082, China
[4]The Second Engineering Company of CCCC Fourth Harbor Engineering Co., Ltd, Guangzhou 510230, China

*Corresponding author email address:zmingxing@cccc4.com

Abstract. Gravity-type quay walls are widely used in port projects around the world because of their advantages of durability and convenience of construction. However, these quay structures are often subject to vibration damage from activities like ground treatment construction, pile driving and traffic vehicle vibration. It is necessary to conduct a reasonable quantitative evaluation of the vibration for the quay structures and establish corresponding control standards so that marine structures are within their permissible vibration limits during the life-span construction process and period of service. The current relevant standards and technical codes for vibration control of structures are overviewed, then two sets of vibration control standards for three common gravity-type quay structures from the micro and macro perspectives are put forward, which can provide relevant reference for similar engineering practice in the future.

Keywords: gravity-type quay walls; vibration safety evaluation; vibration control standard.

1 Introduction

Gravity quay is a type of quay that is widely used in port engineering projects around the world because of its durability, convenience of construction and low maintenance costs. According to different types of quay structures [1]-[2], gravity quays are divided into blockwork quays, caisson quays, L-type quays, sitting bed type cylindrical quays, cast-in-site concrete structures and masonry structures, and the first three are more commonly used. With the rapid development of modern industry and transportation, the use of gravity-type quay walls is becoming more and more frequent. Usually, the soil behind the quay structure needs to be reinforced. The vibration hazard problem of existing quay structures caused by artificial vibration sources such as foundation treatment construction vibration, piling construction, and traffic vehicle vibration is

P. Xiang et al. (eds.), *Proceedings of the 2023 5th International Conference on Hydraulic, Civil and Construction Engineering (HCCE 2023)*, Atlantis Highlights in Engineering 26,
https://doi.org/10.2991/978-94-6463-398-6_74

becoming more and more prominent. If the vibration of the quay structure exceeds its permissible vibration threshold, a series of damage or destruction may occur to the marine structures: slippage, overturning, cracking of the wall, cracks in structural components, etc., which may endanger the integrity of the entire quay structure and its safety, then causing immeasurable losses. Therefore, it is very necessary to make a reasonable evaluation of the impact of construction vibration on the gravity-type quay walls, and establish corresponding vibration control standards so that hydraulic structures are within the allowable vibration threshold range during the entire construction process and service period.

At present, vibration safety evaluations are mainly focused on the impact of blasting vibration on the surrounding existing structures [3]-[5], while the evaluation of the impact of construction (non-blasting vibration) on the safety of marine structures (such as gravity-type quay walls), has not yet formed a unified norm or standard. Regarding the vibration impact of ordinary buildings, some developed countries such as Britain, Germany, the United States, and Japan have successively proposed control standards for building vibration effects. The Chinese national standard [6] stipulates that the time-domain signal test of the vibration velocity of the building structure foundation and the top floor should take the vertical and horizontal two main axis directions, and the evaluation index should take the maximum value of the three peaks and the corresponding vibration frequency.

Based on the above background, this paper intends to study the vibration safety evaluation methods and vibration control standards for these three common gravity-type quay walls (blockwork, caisson, and L-type quay structures).

2 Vibration safety evaluation for gravity-type quay walls

The physical quantities that describe vibration mainly include vibration frequency, vibration intensity (acceleration, velocity, displacement, etc.), vibration direction, and exposure time. The physical quantities that describe the vibration intensity include displacement, velocity, and acceleration. The impact of vibration on structures and human bodies is actually the result of vibration energy conversion. The effective value of acceleration can better reflect this situation. Therefore, in the analysis of environmental vibration, the vibration intensity is generally expressed by the effective value of acceleration, often in m/s^2.

2.1 Vibration safety evaluation for buildings

The Chinese national standard *Standards for Allowable Vibration of Construction Engineering* (GB 50868-2013)[6] stipulates that for the impact evaluation of building construction (here refers to piling, foundation treatment, etc.) vibration on the building structure, the vibration velocity of the building structure foundation and the top floor The domain signal test should take the vertical and horizontal two main axis directions, and the evaluation index should take the maximum value of the three peaks and the corresponding vibration frequency, that is, the Chinese standard is to quantitatively evaluate the vibration impact of the building through the vibration velocity index , and according to the allowable peak vibration velocity when different building types are affected by different building construction vibrations.

The German standard DIN 4150-3[7] also uses the vibration velocity to evaluate the vibration of the building. This standard defines the peak quasi-vector sum of the particle velocity as follows:

$$v_r = ({v_x}^2 + {v_y}^2 + {v_z}^2)^{1/2} \tag{1}$$

In the formula, v_x, v_y, v_z respectively represent the measured peak velocity of the particle in the x, y, z directions.

Since the maximum values of the vibration components in three directions of the same mass point rarely appear at the same time in actual engineering, many people think that the definition of v_r is not very reasonable after research. For the convenience of comparison, some scholars suggest to use the following conversion formula to convert v_r and v_z,

When the vertical component dominates: $v_z = (0.6{\sim}1.0)v_r$

When the horizontal component dominates: $v_z = (0.0{\sim}0.6)v_r$

This German standard stipulates that when the vibration frequency is 1Hz~10Hz, the control standard of the vibration velocity amplitude is 20mm/s. The vibration velocity control standard converted from the above formula in the German standard should be 12mm/s for industrial buildings.

2.2 Vibration safety evaluation for gravity-type quay walls

The structural type of gravity quay is different from that of general buildings. There is no unified vibration evaluation method and control standard at present, and it is necessary to do some exploration on this. According to the severity of port engineering failure consequences, the Chinese standard *Unified Standard for Reliability Design of Port Engineering Structures* (GB 50158-2010) [8] divides the safety levels of port engineering structures into first, second and third levels, as shown in Table 1:

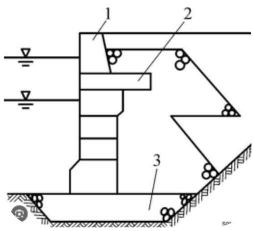
Table 1. Safety class of port engineering structure.

Security level	Consequences of failure	Scope of application
1st level	Very serious	Structures with special safety requirements
2nd level	Serious	General port engineering structures
3rd level	Nothing serious	Temporary port engineering structures

According to the quay structure design code, one of ways to assess the vibration safety are as follows: In order to improve the shortcomings of a single index in evaluating structures affected by vibration , a comprehensive evaluation index[9] can be used to comprehensively consider the three indexes of vibration frequency, vibration acceleration and vibration displacement, and for different quay structures, the above-mentioned several indexes use different weight coefficients, and finally put forward a concept of comprehensive safety, and then evaluate the influence of vibration on quay structures.

According to the *Design Code for Wharf Structures* (JTS 167-2018)[1], the calculation contents of the persistent combination of the ultimate state of the gravity quay bearing capacity include:(1) The anti-tilt stability of the front toe for each horizontal joint and tooth joint on the bottom surface of the wall and the wall body;(2) The anti-sliding stability of the horizontal joints along the bottom surface of the wall and the wall body;(3) Anti-slip stability along the bottom surface of the foundation bed;(4) Bearing capacity of foundation bed and foundation;(5) overall stability;(6) Bearing capacity of components such as unloading plates, caissons, buttresses, hollow blocks and cylinders.

2.2.1. Vibration safety evaluation for gravity blockwork quay. The block type gravity quay is a shore wall type gravity quay composed of prefabricated regular hexahedral voxel concrete, masonry or reinforced concrete solid or hollow blocks (see Figure 1). Its advantages are good durability, no need for steel, simple construction, and no need for complicated construction equipment. There are three types of cube quays: ladder type, balance weight type, and unloading plate type. Take the unloading plate type cube quay as an example.



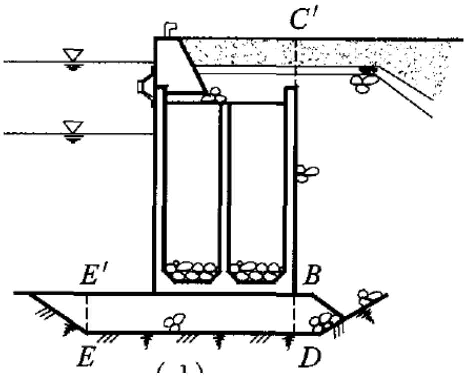
1- breast wall; 2- relieving slab; 3- foundation bed

(a) Typical cross-sectional diagram

(b) Actual picture

Fig. 1. Gravity blockwork quay.

2.2.2. Vibration safety evaluation for gravity caisson quay. The caisson is a huge empty box with a bottom, and the inside of the box is divided into several compartments by vertical and horizontal partition walls (see Figure 2). Rectangular caisson gravity quay is simple to manufacture, has good floating stability and mature construction technology, and is often used as a quay type quay. According to different shapes, caisson quays are mainly divided into rectangular caissons and circular caissons. For the pier type quay, the circular caisson is compared with the square caisson, the former bears the horizontal force without direction, the stress state is good, and the material is saved. According to the actual statistics, the cost of circular piers is about 20% lower than that of corresponding square piers. Therefore, this specification recommends the use of circular caissons.

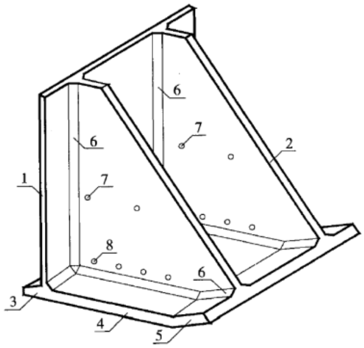


(a) Typical cross-sectional diagram

(b) Actual picture

Fig. 2. Gravity caisson quay.

2.2.3. Vibration safety evaluation for L-type gravity quay. The L-type quay is a reinforced concrete structure formed by connecting vertical plates, bottom plates and ribs (see Figure 3). The ribs can be divided into single ribs, double ribs and multi-ribs. The L-type quay is mainly composed of three parts: concrete parapet, reinforced concrete L-type and sand filling. In the design of L-type quay, anti-sliding and anti-tilting stability checks are required. The main functions of the L-type quay include the horizontal component force of earth pressure filling and surcharge and the overturning moment caused by it, the horizontal component force of mooring force and the overturning moment caused by it.



1- frontal panel; 2- rib plate; 3- toe plate; 4 - inner base slab; 5 - tail plate; 6 - reinforcement angle; 7- hanging hole; 8 - water hole

(a) Typical cross-sectional diagram

(b) Actual picture

Fig. 3. Gravity L-type quay wall.

3 Research on vibration control standard for gravity-type quay walls

3.1 Vibration control standards for buildings

Since the vibration of the building is not only related to the ground vibration transmitted to the foundation of the building, but also related to the strength, material properties and dynamic characteristics of the building structure itself, it is almost impossible to formulate a more accurate and unified vibration control standard. It often happens that when a certain standard is used for evaluation, the physical quantity of vibration may be within the required range, while when other standards are used, the vibration may exceed the threshold.

Since various standards are universal standards formulated on the basis of data obtained from experiments on specific structures under a specific site condition, there are large differences in the standards formulated by various countries, which are summarized in Table 2.

Table 2. Maximum allowable peak particle velocity (PPV) values for transient vibrations to prevent structural damage.

Reference	Frequency range (Hz)	Structure and condition	Allowable PPV (mm/s)
Eurocode 3 (BS EN 1993-1-1:2005)[10]	All frequencies	1) Reinforced or framed structures–industrial and heavy commercial buildings	50
		2) Buried services	40
		3) Heavy industrial	30
		4) Light commercial	20
		5) Residential	10
		6) Ruins, building of architectural merit	4
British Standard BS 7385–2:1993[11]	4-15	1) Unreinforced or light framed structures, residential or light commercial type buildings	15-20
	>15	2) Unreinforced or light framed structures, residential or light commercial type buildings	20-50
Swiss Standard SN 640312 (SNV 1992)[12]	10–30	1) Buildings in steel or reinforced concrete, such as factories, retaining walls, bridges, steel towers, open channels, underground chambers, and tunnels with and without concrete alignment	30.48
		2) Buildings with foundation walls	17.78
		3) Buildings as mentioned previously but with wooden ceilings and walls in masonry	12.7
		4) Construction very sensitive to vibration, objects of historical interest	7.62
AASHTO (1990)[13]	-	1) Engineered structures, without plaster	25.4–38.1
		2) Residential building in good repair with gypsum board walls	10.16–12.7
		3) Residential buildings, plastered walls	5.08–7.62
		4) Historic sites or other critical locations	2.54
Chinese Standard (GB 50868-	1-50	1) Industrial buildings, public buildings	24.0
		2) Residential buildings	12.0
		3) Buildings that are sensitive to vibration, have	6.0

2013)[6]		protection value, and cannot be classified into the above two categories	
Chinese Standard (GB 6722-2014)[14]	1-50	1) Earth cave dwellings, adobe houses, rubble houses	1.5-9.0
		2) General civil buildings	15.0-25.0
		3) Industrial and commercial buildings	25.0-45.0
		4) Central control room equipment of hydropower stations and power plants in operation	5.0-7.0
		5) Hydraulic tunnel	70-100
		6) Traffic tunnel	100-150
		7) Permanent rock high slope	50-120
		8) General ancient buildings and monuments	1.0-3.0

3.2 Vibration control standards for gravity quay walls

Refer to the permissible vibration velocity limits of buildings involved in Table 2, combined with the relevant provisions of the *Code for Construction Monitoring Technologies on Port & Waterway Engineering* (JTS/T 234-2020) and *Standard for Vibration Control Design of Industrial Buildings* (GB 50190-2020), from the micro level vibration control standards of common gravity-type quay walls are given respectively. From a microscopic point of view, the allowable vibration acceleration of the quay structure foundation and the allowable vibration displacement of the top surface of the quay structure are used as control indicators, as shown in Table 3. From a macro perspective, the early warning value of the internal force of the structural components of the quay and the horizontal displacement of the top of the quay structure are used as control indicators, as shown in Table 4.

Table 3. Permissible limits of vibration for gravity-type quay walls.

Quay structure type	Blockwork	Caisson	L-type
Allowable vibration acceleration on foundation (m/s^2)	3.0	4.0	3.5
Allowable vibration displacement at the top (mm)	0.2	0.3	0.25

Table 4. Vibration control limits for gravity-type quay walls.

Quay structure type	Blockwork	Caisson	L-type
Early warning value of internal force of structural members (percentage of design value of bearing capacity)	60%	70%	65%
Horizontal displacement limit at the top of the structure (ratio of the height of the quay structure)	1/400	1/500	1/450

4 Conclusion

(1) The current research of vibration safety evaluation of buildings and structures is reviewed, and the vibration safety evaluation methods of three common gravity-type quay walls, namely blockwork, caisson and L-type, are proposed.

(2) With the reference of concept of different countries' norms and standards related to vibration control of structures, two sets of vibration control standards are proposed for three common gravity-type quay walls from the micro and macro perspectives, which can provide relevant reference for other similar engineering practice.

References

1. JTS 167-2018, Design Code for Wharf Structures[S].
2. Maritime works — part 2: Code of practice for the design of quay walls, jetties and dolphins[S]. BS 6349-2 2010. BSI Standards Publication.
3. Wang M M, Pan X M, Zhang C M, Wen X D and Wang D K. Study on Blasting Vibration Response of Adjacent Tunnels[J]. Rock and Soil Mechanics, 2004(03): 412-414. DOI: 10.16285/j.rsm .2004.03.017.
4. Zhang Y Q, Jiang N, Zhou C B, Wu T Y, Luo X D and Xia Y Q. Dynamic Response of Subway Foundation Pit Blasting Vibration Adjacent High-Rise Frame Building[J]. Journal of China Coal Society,2019,44(S1): 118-125.DOI:10.13225/ j.cnki.jccs.2019.0261 .
5. Zhong Q, Li J L and Wang Y C. Monitoring and analysis of impact of blasting vibration on adjacent hydraulic structures[J]. People's Changjiang,2015,46(10):83-86. DOI: 10. 16232/ j.cnki .1001-4179.2015. 10.020.
6. GB 50868-2013, Standards for Allowable Vibration of Construction Engineering[S].
7. Part S V. 3: Effects of vibration on Structures[J]. DIN Germany Institute, 1999: 4150-3.
8. GB 50158-2010, Unified Standard for Reliability Design of Port Engineering Structures[S].
9. Zhang W W. Research on vibration safety evaluation method of hydraulic drainage structures[D]. Nanchang University, 2014.
10. Eurocode 3: Design of steel structures. BS EN 1993-1-1:2005.
11. British Standards Institution. Evaluation and Measurement for Vibration in Buildings: Guide to damage levels from groundborne vibration[M]. BSI, 1993.
12. SN 640312-1992. Swiss Association for Standardization (SNV). Swiss standard for vibration in buildings. SN 640 312. Switzerland: Winterthur; 1978.
13. Aashto. Standard recommended practice for evaluation of transportation-related earthborn vibrations. Washington, DC: AASHTO Designation R8-96; 2009.
14. GB 6722-2014, Safety Regulations for Blasting[S].