Advanced Materials Research Vol. 935 (2014) pp 207-210
© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.935.207

Lessons from Sukur Vernacular Architecture: A Building Material Perspective

Yakubu Aminu Dodo[8], Mohd Hamdan Ahmad, Mansir Dodo, Faizah Mohammed Bashir and Suleiman Aliyu Shika

Department of Architecture, Faculty of Built Environment, Universiti Teknologi Malaysia, Malaysia

Professor & Executive Director, Institute Sultan Iskandar Universiti Teknologi Malaysia Johor-Bahru, Malaysia.

Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria, Nigeria

Centerfor Real Estate Studies, Universiti Teknologi Malaysia, Malaysia

[a]dyaaminu@yahoo.com, [b]b-hamdan@utm.my[A] [c]mansirdo14@yahoo.com,
[d]faizahbash@yahoo.comm, [e]asshika1 @gmail.com,

Keywords: Building Materials, Sukur, Sustainable Architecture, Vernacular architecture.

Abstract. This study presents the lessons from the vernaculars Architecture of sukur kingdom with a focus on the use of building materials as a sustainable means for solving problems facing present-day architecture in issue of sustainability; in particular the critical housing situation in the developing countries. Through a case study of the ancient vernacular Architecture of sukur the result shows that stakeholders in the construction industry could reflect on how this building materials and the techniques in operation in their region by translating it in a modern way to address those striking design problems through solving them from the masters' builders.

Introduction

Buildings all over the world have significant impacts on the environment and natural resources [1]. To such, [2, 3] assert that buildings account for 45% of worldwide energy use, 80% of potable water use, and 50% of the timber harvest in North America. They further assert that buildings account for about 40% of municipal solid waste and 30% of greenhouse gas emissions in the United States (U.S) that contribute to global warming. Hence, the emerging world energy issues and environment challenges demand a substantial revolution of building design philosophies, strategies, technologies, and construction methods.

The use of locally available building materials and traditional building methods harnesses the use of natural energy that can bridge the gap between traditional achievements and modern needs. One of such application that has evolved intuitively is Vernacular architecture which is a category of architecture based on localized needs and construction materials reflecting local traditions. According to [4], vernacular architecture is architecture specific to a country and a people. Vernacular architecture has evolved over time in North Eastern Nigeria to reflect the environmental, cultural, technological, and historical context of the African Sub-region. Such is so because design decisions have been influenced by traditions in the prevailing culture through a long period of trial and error and the creativity of local builders who possess specific knowledge about their place. Results have yielded combined comfort and beauty, social and physical functionality and the substitution of modern materials most a times having environmental impacts [5].

This paper demonstrates the ways in which Sukur vernacular architectural forms can be of use in solving problems facing present-day architecture, in particular the critical housing situation in the developing countries.

Sukur

Sukur is Africa's first cultural landscape to receive World Heritage List inscription 'Sukur' means "vengeance" in Margi and Libi languages. It also means "feuding" in the Bura language that occurred among the Sukur people. In the lower part of the settlement, village huts are simple circular structures of common folk, made of clay with roof of thatch, and with woven floor mats. A group of such houses are surrounded by a compound wall of low height. The key features of the cultural landscape have not been significantly modified since they were laid down. The way in which they have been maintained since that time has been in traditional form using traditional materials and techniques. The stone structures in form of houses, farm terraces and walkways still remain the most distinct feature of Sukur landscape.

Aim

To elaborate the materials used in the vernacular Architecture of Sukur as it relates to sustainability issues and with a focus on the use of building materials as a sustainable means for solving problems facing present-day architecture.

Method

Through a case study of the ancient vernacular Architecture of sukur; documentation of the buildings, materials used was carried out and interview was carried out with the chief son and one of the custodian of the sukur kingdom.

Discussion

Vernacular architecture also called 'folk architecture' derived out of various factors of a region (such as environmental, social, cultural, technological, etc.) giving more importance to local specific factors (such as climate and topography) in design and construction technique. [6], asserts that buildings of present architectural style that use modern materials and technology results in high energy consumption in an attempt to provide thermal comfort indoors. The vernacular architecture at any place on the other hand has evolved through ages by consistent and continuous effort for more efficient and perfect solutions in the architectural process. Experimental and numerical studies also report that vernacular architecture gives solutions that are in perfect harmony with nature.

According to [7], in the Nigerian context, vernacular architecture in the North is expressed informs deriving from the culture influences of Brazil, North Africa Sudan and Europe. These forms have a traditional base in the socio-cultural organization of the Nigerian society and the interaction between it and the other influences have crystallized into the Nigerian vernacular architecture. Some of the basic materials used in vernacular architecture in Northern Nigeria according to [8] are:

a. Stone: used for structural purpose, for foundation, decorations, temples and other worship places;
b. Mud: adobe *daga, pise* are also referred to as mud used for walls, roofs and sometimes furniture;
c. Vegetable Materials: for roofing, reinforcement and whole building construction as that of the pastoralist (Fulani) which are portable and dismountable; and
d. Modern Materials: due to changes in population over the time and the impact of the colonial masters materials like Zinc for roofs Louvers for windows.

Vernacular architecture in Northern Nigeria requires an interdisciplinary approach due to the fact that it not only covers over 200 different tribes and group but that materials available are basically in anthropological forms. Construction using vernacular architecture in Northern Nigeria is based on cooperative venture skills translated from the older generation which have developed carefully over a long period of time. As such, various building styles have evolved which include; Sudanese Style, Impluvial Style, Hill Style and the Beehive Style [8, 9].

Sukur vernacular architecture

Sukur is located in the Mandara Mountains under Madagali Local Government Area of Adamawa State, North-eastern Nigeria. Sukur is listed on UNESCO's World Heritage Sites lists in 1999 because of its exceptional landscape illustrating a form of land-use that marks a critical stage in human settlement and its relationship with its environment. Sukur cultural landscape is also an eloquent testimony to a strong and continuing spiritual and cultural tradition that has endured for many centuries in North Eastern Nigeria. Sukur houses the palace of the Hidi (Chief) on the hill dominating the villages below the terraced fields and their sacred symbols. Sukur landscape has survived unchanged for many centuries and is a good surviving example of a strong traditional cultural system that has managed to survive. This is a clear representation of suggestions by [10] that human beings should adapt all their design activities to the natural order of the global system. Figure 1 depicts the Landscape of Sukur kingdoms.

Figure 1: Ancient vernacular architecture: characteristics categorization source [1]

Figure 2: Entrance to the kingdom source authors field work

Figure 3: Main entrance to the palace source authors field work

Figure 4: One of the granary of the kingdom source authors field work

Summary

Sustainable architecture suggests that human beings should adapt all their design activities to the natural order of the global system. In view of this, vernacular architecture can be a most appropriate process to perform the role of stabilizing our ecological system. This paper illustrates how the

Sukur people have used stone for building construction for over centuries. Numerous lessons could be learnt from their ways of building and translated to our modern day technology which can enhance how we build our residential buildings in a most sustainable manner [11]. Conscious efforts must be made by stakeholders in the construction industry on how to design and construct buildings that sustainably utilise passive techniques in operation.

Conclusion

This paper demonstrates the ways in which Sukur vernacular architectural forms can be of use in solving problems facing present-day architecture, in particular the critical housing situation in the developing countries. Stakeholders in the construction industry should reflect on how to utilise passive techniques in operation in their region and translate it in a modern way to address those striking design problems through solving them from the masters' builders.

Acknowledgements

We would like to thank the chief of the Sukur Kingdom for allowing us to explore the architectural edifice of his kingdom and Dr. Okoronka of the department of Education technology Adamawa state University Mubi Nigeria for his guidance through successions of the seven hills to the Sukur kingdom

References

[1] Zhai, Z. & Previtali J. M. Ancient vernacular architecture: characteristics categorization and energy performance evaluation Energy and Buildings 42 (2010) 357–365.

[2] Edward, B. Rough guide to sustainability. London: RIBA Enterprises. (2007).

[3] Kandar, Z. M. Towards green buildings appreciations: a paper presented in the seminar series of the department of geoinfomatics Universiti Teknologi Malaysia, April 2010, UTM Malaysia. (2010)

[4] Langley. Changes in the Production of the Built Environment in Rural Areas. In African Environment, London, 2 (1976)37-51

[5] Fathy, H. Natural energy and vernacular Architecture University of Chicago Press, 5801 Ellis Ave., 4th Fl., Chicago, IL 60637. (1986)

[6] Dodo, Y. A., Bashir, F. M., and Ogunsote, O. O. Stone as a Building Material For Sustainable Vernacular Architecture in North-Eastern Nigeria; WABER Book Chapter London(2011).

[7] Prucnal-Ogunsote, B. Reflection of Culture and Climate in the Vernacular and Modern Architecture of Akure. Federal University of Technology, Akure. 14-19 August, 2005.

[8] Denyer, S. African Traditional Architecture: an anthropological perspective. Heinemann, 1978.

[9] Oliver, P. (Ed.) Encyclopedia of the Vernacular Architecture of the World, Cambridge University Press, New York, 1997.

[10] Dili, A.S. Naseer, M.A. Varghese T. Z. Passive environment control system of Kerala vernacular residential architecture for a comfortable indoor environment: A qualitative and quantitative analyses Energy and Buildings 42 (2010) 917–927

[11] Koenigsberger, O. H., Ingersoll, T. G., Mayhew, A. and Szokolay, S. V. Manual of tropical Housing and Building-Climatic Design, Orient Longman Private Limited, ISBN: 978-81-7371-697-3 (1975).

Advanced Materials Research Vol. 935 (2014) pp 211-214
© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.935.211

Theoretical study on cable's vibration control by single TMD

Liang Dong[1,2,a] and Song Jixiang[1,b]

[1]Dept. of Civil Engineering, Hebei Univ. of Technology, Tianjin 300130, China

[2]Civil Engineering Technology Research Center of Hebei Province, Tianjin, 300401, China

[a]ldhebut@gmail.com, [b]798071923@qq.com

Keywords: stay cable, vibration mitigation, tuned mass damper (TMD), modal damping ratio, complex modal analysis.

Abstract. The commonly used viscous dampers for cable's vibration mitigation have some unfavorable factors, such as the damping effect is not obvious for super long stay cable, the limitation of installation position, coupling vibration, etc. The cable-tuned mass damper system vibration model is put forward to solve this problem. The optimal cable-tuned mass damper system modal damping ratio and optimum design parameters, including cable vibration order, TMD's stiffness, TMD's mass, and TMD's damping, were obtained by the method of complex models. The results can provide important reference for the design of TMD for stay cable.

Introduction

Stay cable is the main component of cable-stayed bridge, which is under huge tension and has extremely important influence on bridge's safety. But, it is flexible with light weight and small damping. Complex coupled vibration in the wind, rain, vehicles, bearing incentives under the effect of external factors is likely to happen [1]. Cable's vibration with big amplitude result in large deformation, especially in the anchorage point. It may cause internal strand fatigue damage. In order to prevent cable's vibration, different types of dampers are needed to install, and this mechanical damping measures have been applied in more than a dozen bridges.

Many researchers have studied the performance of linear viscous dampers in terms of the modal damping level achieved after it is attached to a stay cable. For an ideal taut cable, a universal estimation curve has been estimated to relate the modal damping ratio and the damper size [2]. An analytical formula has been derived to estimate the optimal damper design for a given cable configuration and attachment location [3]. The individual and combined effects of realistic parameters such as cable sag, damper stiffness, cable flexural rigidity, and damper support stiffness have also been explicitly taken into consideration in the design formulas of linear damper[4]. Recently, a semiactive damper has been studied theoretically as an alternative to a transverse passive viscous damper for reducing cable motion, and it may be a potential method to reduce the cable motion dramatically [5]. Wu, W.J. and Cai, C.S studied the effects of TMD and MR damper on cable's vibration mitigation through experiments [6, 7]. TMD can overcome the limitation of installation location and other shortcomings effectively. Therefore, it is necessary to study the performance of cable-TMD systems in order to offer valuable reference for applications design accordingly.

Problem Formulation

Consider a dynamic system composed of an inclined taut cable and a TMD, as shown in Fig.1. For simplicity, the cable's sag, bending stiffness and inner damping are not considered in this study. Only the in-plane small amplitude vibration $V(x, t)$ of the cable is of interest. The cable has a mass per unit length m, a length L, inclination θ, and tensile force T. The distance between the TMD and deck is l_T.

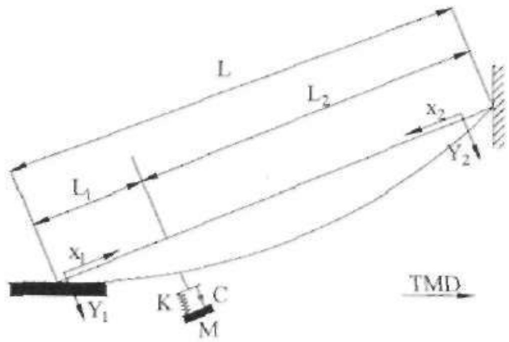


Fig.1 Theoretical model composed of cable and TMD

To facilitate derivation, x-axial direction is along the cable, and the vertical direction is the y-axis. Defined a complex characteristic frequency ω, then the differential equations of the cable is expressed as

$$\frac{d^2V_k(x_k)}{dx_k^2}=-\omega^2\frac{m}{T}V_k(x_k) \tag{1}$$

At the location of the damper there is a discontinuity in the inclination of the cable, it requires:

$$v_1(l_1,t)=v_2(l_2,t)=\gamma \tag{2}$$

where γ is the amplitude of the cable at TMD point. Introducing complex wave number in the vibration system, the differential motion equations of the cable-TMD system is expressed as:

$$\begin{cases} T\left(-\left.\frac{\partial v_1}{\partial x_1}\right|_{x_1=l_1}-\left.\frac{\partial v_2}{\partial x_2}\right|_{x_2=l_2}\right)=K\left(v_1|_{x_1=l_1}-v_d\right)+C\left(\left.\frac{dv_1}{dt}\right|_{x_1=l_1}-\frac{dv_d}{dt}\right) \\ K\left(v_1|_{x_1=l_1}-v_d\right)+C\left(\left.\frac{dv_1}{dt}\right|_{x_1=l_1}-\frac{dv_d}{dt}\right)-M\frac{d^2v_d}{dt^2}=0 \end{cases} \tag{3}$$

in which v_d is the vertical displacement of TMD. For each mode of the cable-TMD system in Fig.1, TMD vertical displacement can be expressed as:

$$v_d=\alpha v_k \tag{4}$$

where α is the complex amplitude ratio of TMD and cable at the position of TMD,

$$\alpha=\frac{1+2\xi\rho i}{1+2\xi\rho i+\rho^2} \tag{5}$$

in which ξ is damping ratio of TMD; $\rho=\omega/\omega_d$ the ratio of cable's frequency and TMD frequency. Introducing the complex wave number $\beta=\omega\sqrt{m/T}$, the complex frequency equation of cable-TMD system can be expressed as:

$$\tan(\beta L)=\frac{\frac{M\alpha\omega^2}{T\beta}\sin^2(\beta l_1)}{M\alpha\omega^2\ \sin(\beta l)\cos(\beta l)-1} \tag{6}$$

Complex modal solution

To analyze factors of modal damping ratio of the cable-TMD system in Fig.1, wave number can be expressed as $\beta_n = \beta_n^0 + \varepsilon$, in which β_n^0 is the wave number without damping $\beta_n^0 = n\pi L$, and ε is the tiny perturbation, then

$$\tan(\beta_n L) = \varepsilon L + o\left[(\varepsilon L)^3\right] = \beta_n L - n\pi \tag{7}$$

Eq.8 can be obtained after simplification by using Taylor series and ignoring high trace,

$$\beta_n L = n\pi + \frac{\alpha \dfrac{M}{mL} n^3 \pi^3 \left(\dfrac{l_1}{L}\right)^2}{\alpha \dfrac{M}{mL} n^2 \pi^2 \dfrac{l_1}{L} - 1} \tag{8}$$

Then, the damping ratios of the cable-TMD system can be expressed as

$$\zeta_n = \frac{\operatorname{Im}(\beta_n L)}{|\beta_n L|} = \sqrt{\frac{4n^4\pi^4\xi^2\rho^6 \dfrac{M^2}{m^2L^2}\dfrac{l_1^4}{L^4}}{\left\{1+(-2+4\xi^2)\rho^2+\rho^4-2n^2\pi^2\left[1+(-1+4\xi^2)\rho^2\right]\dfrac{M}{mL}\dfrac{l_1}{L}+n^4\pi^4(1+4\xi^2\rho^2)\dfrac{M^2}{m^2L^2}\dfrac{l_1^2}{L^2}\right\}\cdot \left\{1+(-2+4\xi^2)\rho^2+\rho^4-2n^2\pi^2\left[1+(-1+4\xi^2)\rho^2\right]\dfrac{M}{mL}k_1(1+k_1)+n^4\pi^4(1+4\xi^2\rho^2)\dfrac{M^2}{m^2L^2}\dfrac{l_1^2}{L^2}(1+\dfrac{l_1}{L})^2\right\}}} \tag{9}$$

In this study, let $l_1/L = 0.03 \leq 1$, then Eq.9 can be reformed as

$$\xi_n = 0.017765\sqrt{\frac{b^2n^4\xi^2\rho^6}{(1+(-2+4\xi^2)\rho^2+\rho^4+0.093007b^2n^4(1+4\xi^2\rho^2)-0.60994bn^2(1+(-1+4\xi^2)\rho^2))\,(1+(-2+4\xi^2)\rho^2+\rho^4+0.087668b^2n^4(1+4\xi^2\rho^2)-0.59218bn^2(1+(-1+4\xi^2)\rho^2))}} \tag{10}$$

Relation of cable-TMD system modal damping and parameters of TMD

In this paper, the influence of TMD parameters (such as vibration mode, mass, damping, stiffness, etc.) on the system damping are studied as follow.

Influence of TMD mass on the cable-TMD system modal damping. The mass ratio of TMD and the main structure is about 1% to 5%. This paper extend the ratio to 20% in order to observe the damping effect on the cable-TMD system modal damping. Fig.2 shows the relation between mass ratio and the cable-TMD system modal damping with different vibration mode, where the abscissa is the mass ratio, and the ordinate is the cable-TMD system modal damping.

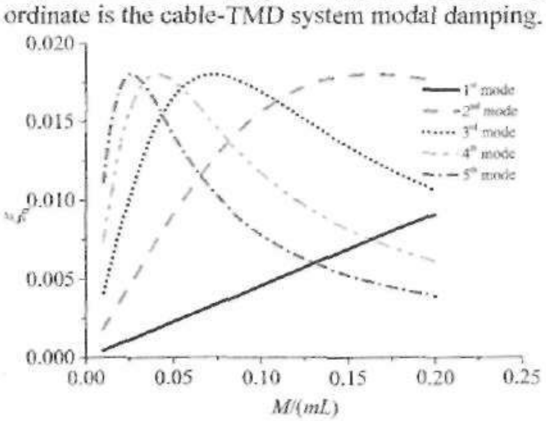


Fig.2 Influence of mass ratio of TMD and cable

The influence of TMD stiffness on the cable-TMD system modal damping. Fig.3 shows the effect of TMD stiffness on the cable-TMD system modal damping, the abscissa is the TMD stiffness in the range of 0.10 to 5.00, ordinate is the cable-TMD system modal damping. From Fig.3, modal damping increases rapidly with the increasing vibration order.

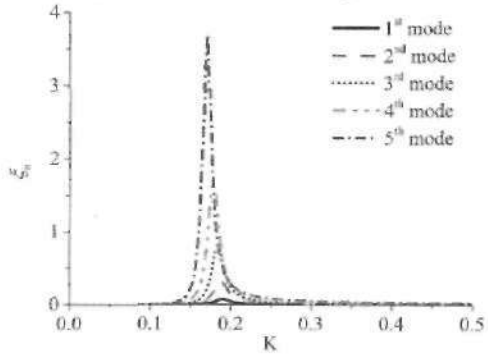


Fig.3 Influence of TMD stiffness

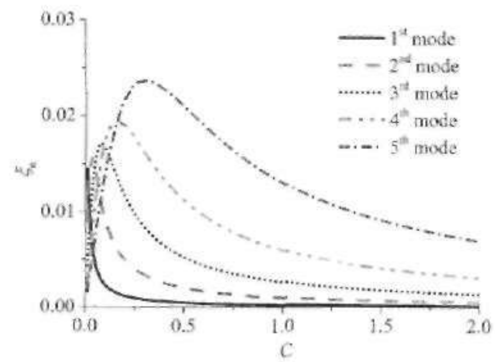


Fig.4 Influence of TMD damping

The influence of TMD damping on the cable-TMD system modal damping. Fig.4 shows the relation between TMD damping and the cable-TMD system modal damping with different vibration mode, where the abscissa is the TMD damping, and the ordinate is the cable-TMD system modal damping. For the purposes to control the cable's vibration, TMD damping exists the optimal value.

Summary

In this paper, a free vibration system composed of cable and a single TMD is established to study the effects of TMD on cable's vibration mitigation. Based on the analysis above, it can be concluded that:

1) TMD can be used to mitigate the cable's vibration with good effects.

2) The stiffness, mass and damping parameters of TMD have a great influence on the cable-TMD system modal damping. All the parameters should be considered during optimization.

3) Results of this paper has important reference for the cable-TMD design.

References

[1] Hiroki Yamaguchi, Fujino, Y., Stayed cable dynamics and its vibration control, in: A. Larsen and S. Esdahl (Eds.), Bridge aerodynamics, Balkema, Rotterdam, 1998, pp.235-253.

[2] Pacheco, B. M., Fujino, Y., and Sulekh, A. Estimation curve for modal damping in stay cables with viscous damper. J. Struct. Eng. 119 (1993) 1961-1979.

[3] Krenk, S. Vibrations of a taut cable with an external damper. J. Appl. Mech. 67 (2000) 772-776.

[4] Krenk, S. and J.R. Hogsberg, Damping of Cables by a Transverse Force. Journal of Engineering Mechanics. 131 (2005) 340-348.

[5] E. A. Johnson, G. A. Baker, J. B. F. Spencer and Fujino, Y., Semiactive Damping of Stay Cables. J Eng Mech. 133 (2007) 1-11.

[6] Wu, W.J., Cai, C.S., Cable vibration control with a semiactive MR damper-numerical simulation and experimental verification. Engineering and Mechanics. 34 (2010) 611-623.

[7] Wu, W.J., Cai, C.S., Comparison of deck-anchored damper and clipped tuned mass damper on cable vibration reduction. Structural Engineering and Mechanics. 32 (2009) 741-754.

Advanced Materials Research Vol. 935 (2014) pp 215-219

doi:10.4028/www.scientific.net/AMR.935.215

Cofferdam construction monitoring of Haihe Bridge

Liang Dong[1,a], Wei Long[2,b] and Du Chuang[1,c]

[1]School of Civil Engineering, Hebei University of Technology, Tianjin, 300401, China

[2]Civil Engineering Technology Research Center of Hebei Province, Tianjin, 300401, China

[a]ldhebut@gmail.com, [b]251780342@qq.com, [c]895277425@qq.com

Keywords: single-wall steel sheet pile cofferdam, construction monitoring, theoretical calculation model, 3D FEM, comparative analysis.

Abstract. The risk of steel sheet pile cofferdam construction is very high, and the collapse often results in heavy casualties. This paper discusses the calculation model of single wall steel sheet pile cofferdam system in detail during construction. Take for instance the R38# pier construction process of Haihe Bridge, the construction monitoring system of the steel sheet pile cofferdam is established to get the deformation and stress of steel sheet pile and supporting system. Comparative analysis between measurable results and 3D FEM results is done, and both are basically consistent.

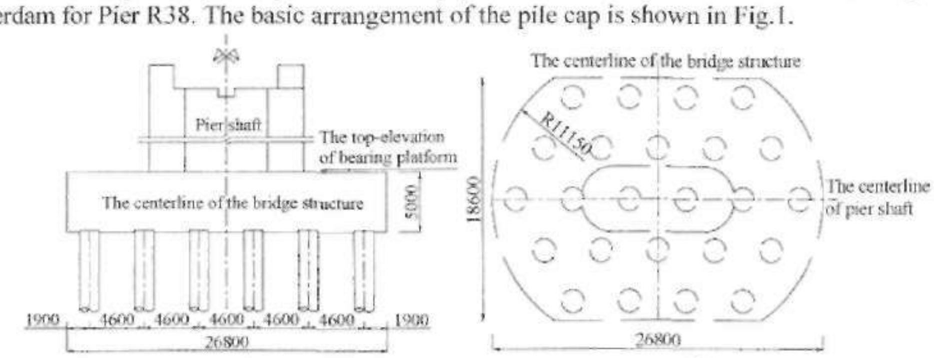
Introduction

Steel sheet pile cofferdam with concrete bottom sealing construction scheme is suitable for sand, gravel, clay soil and weathered rock bed of shallow foundation. It has high strength and can be reused for many times. Steel sheet pile cofferdam is now widely used in the pile cap construction underwater [1,2]. The rapid development of large bridge puts forward higher requirements for construction of large single wall steel cofferdam in the suction process [3].

The cofferdam internal and external pressure difference caused by the river level fluctuations and suction process must be considered carefully in the calculation to prevent structural damage [4,5]. Taking single wall steel cofferdam used in pier cap R38 of Haihe Bridge as the example, this paper compared monitoring results and FEM results to judge the safety of cofferdam in time, and make it clear the weak link in the whole construction process. This paper has great theoretical and practical reference value for the construction of similar structures.

Project overview

The superstructure of Haihe Bridge is a prestressed concrete continuous beam with three spans (100 +160+100m). Bored pile group foundation with 24 piles in 6 rows is used. The length of pile is 88m and the depth of pile cap is 5m. This paper discussed the construction monitoring of steel cofferdam for Pier R38. The basic arrangement of the pile cap is shown in Fig.1.



(*a*) (*b*)

Fig.1 The layout of the main-pier foundation /mm (*a*: the elevation view; *b*: the plan view)

This bridge is located in the Haihe River. The fluctuation amplitude of water level is small, and the flow is very slow. The highest water level is +2.5m. According to the geological survey report, the parameters of geological layer and soil layer around R38 pier are listed in Table 1.

Table 1 The soil parameter table of R38-pier

No.	Soil layer	Layer top elevation (m)	Layer bottom elevation (m)	Density (kN/m^3)	Internal friction angle (°)	Cohesion (kPa)
1	Silty soil	-0.32	-2.12	18.7	7.6	0
2	Silt	-2.12	-9.42	19.6	24.2	12.7
3	Silty soil	-9.42	-10.82	18.7	8.4	2.3
4	Silty clay	-10.82	-22.42	19.6	24.2	12.7

Construction monitoring of steel sheet pile cofferdam

Design of the steel sheet pile cofferdam. The type of Larsen VI was used with length of 18m. The size of cofferdam is 21.6×28.8m. The top elevation of the cofferdam is +2.5 m and the bottom elevation is -15.5m. Three inner supporting are set as shown in Fig.2.

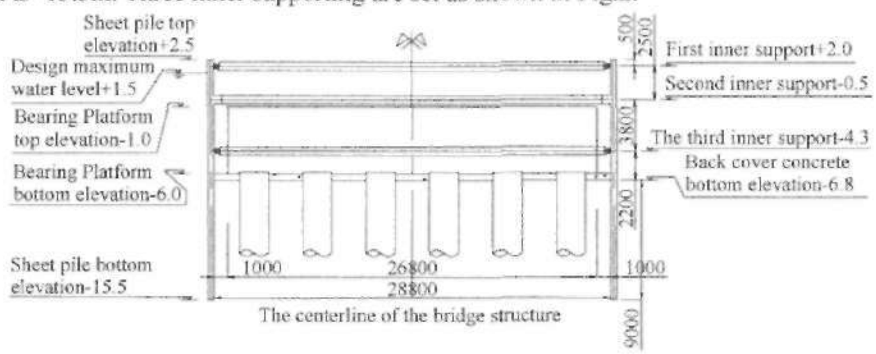


Fig.2 The elevation of the steel sheet pile cofferdam /mm

Gauging point arrangement. The gauging points are arranged on the steel sheet pile, ring beam and inner supporting in order to achieve the overall stress and displacement distribution of the cofferdam. Four steel sheet piles located at the midpoint of each side were selected to set the gauging points which include two displacement gauging points and two stress points. The position of gauging points on ring beam and inner supporting was determined by internal forces, the importance of component, and dangerous level. The JMZX-206A sensors with high waterproof performance were used on steel sheet piles, and JMZX-212A sensors were used on the ring ream and inner supporting. The arrangement of sensors are shown in Fig.3. The actual sensors are shown in Fig.4.

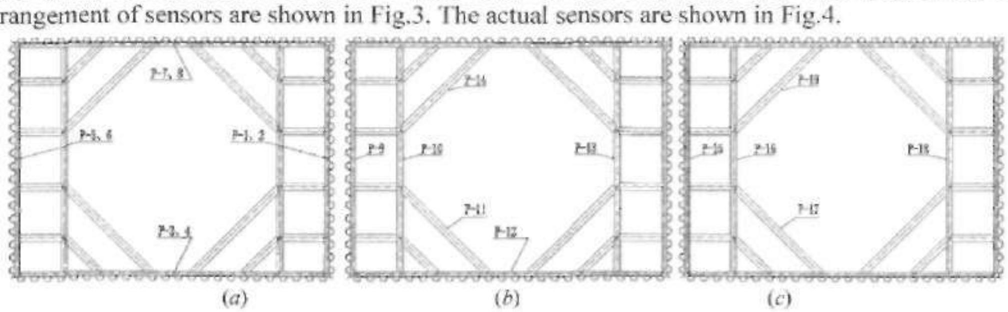


Fig.3 Gauging points on steel sheet pile (*a*: Gauging points on steel sheet pile; *b*: Gauging points on the 2nd ring beam and inner supporting; *c*: Gauging points on the 3rd steel sheet pile)

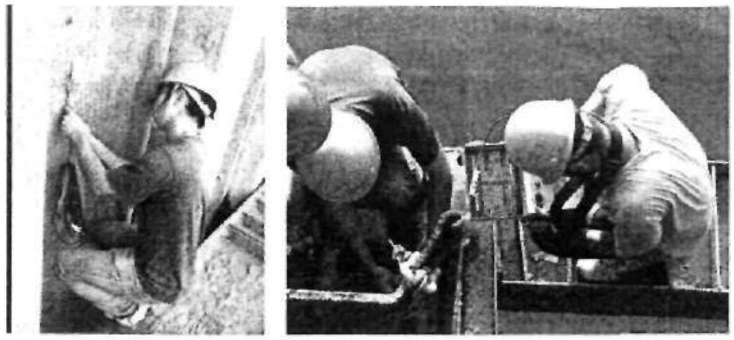


Fig.4 Installation of sensors and measuring

Typical conditions

According to the cofferdam construction steps, the construction process is divided into 5 typical conditions. The contents and sensor installation each step are shown in Table 2.

Table 2 Construction steps and sensor mounting

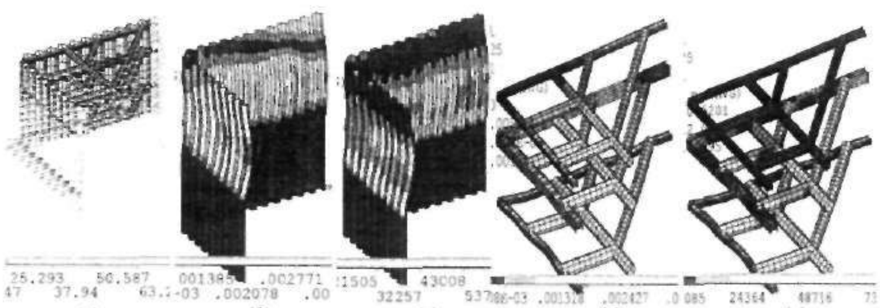
Case	Important construction content	Description of the sensors
I	Positioning and piling of the steel sheet pile	Installation of 8 sensors (P1-P8 in Fig.3) on the steel sheet pile and record the data
II	First inner supporting installation, cofferdam excavation to-1.5m	Measuring
III	Second inner supporting installation, cofferdam excavation to-4.8m	Installation of 6 sensors (P9-P14 in Fig.3) on the second inner supporting and measuring
IV	Third inner supporting installation, cofferdam excavation to-6.8m	Installation of 5 sensors (P5-P19 in Fig.3) on the second inner supporting and measuring
V	Removing the 3rd inner supporting, and pumping water out of the cofferdam	Measuring

According to the above typical working conditions, the maximum stress and deformation of the inner supporting, ring beam, and steel sheet pile are measured.

Theoretical Analysis

Assumptions and basic parameters. The steel sheet pile is fixed under the cushion concrete surface. The SkSP-SX27 sheet pile is used in this project. The section parameters of SkSP-SX27 can be gotten from relevant codes and standards.

FEM model. The FEM model shown in Fig.5(a) was used to calculate the stress and displacement according to the typical working conditions in Table 2. Only 1/4 of the whole cofferdam was modelled because of structural symmetry. Shell element was used to simulate the steel sheet pile, and beam element for internal supporting and ring beam. Fig.5 (b)~(e) give the calculation results by nephogram.



(a) (b) (c) (d) (e)

Fig.5 The calculation model and analysis results of R38 steel cofferdam (*a*. FEM model; *b*. Sheet pile deformation nephogram; *c*. Stress nephogram of the steel sheet pile; *d*. Inner supporting deformation nephogram; *e*. Inner supporting stress nephogram)

Result Analysis

The maximum stress and displacement of steel sheet pile and inner supporting each typical working condition from calculation and measurement are shown in Table.4, in which SSP refers to steel sheet pile, and IS refers to inner supporting.

Table.3 The comparison of stress and displacement of steel sheet pile and inner supporting

Case	Value source	σ_{maxSSP} [MPa]	δ_{maxSSP} [mm]	σ_{maxIS} [MPa]	δ_{maxIS} [mm]
II	Theoretical	33.46	2.74	13.78	0.50
	Measured	28.19	2.53	12.20	0.42
	Relative error	15.8%	7.7%	11.5%	16.0%
III	Theoretical	141.03	13.87	61.84	3.91
	Measured	135.86	11.56	50.35	3.56
	Relative error	3.7%	16.7%	18.0%	9.0%
IV	Theoretical	96.77	6.23	109.60	5.20
	Measured	86.77	5.23	99.98	4.78
	Relative error	10.3%	16.1%	8.8%	8.1%
V	Theoretical	120.23	10.69	50.40	3.12
	Measured	111.34	9.14	43.74	2.68
	Relative error	7.4%	14.5%	13.2%	14.1%

There is some little difference between the FEM value and the measured value. The maximum absolute difference of stress is 11.49MPa, the corresponding relative error is 18.0%; and the maximum absolute difference of displacement was 2.31mm, the corresponding relative error is 16.7%.

Conclusions

Based on above analysis, the following conclusions can be drawn:

1) For a large single wall steel cofferdam, it is very necessary to control the important construction process by monitoring means, which will guarantee the safety during construction;

2) The calculation model used in this paper is reasonable;

3) Analysis results show that the maximum deformation of the cofferdam is at the midpoint of the long edge of the support and selecting the larger bending moment of inertia inner support is important to ensure the construction process safety;

4) The theoretical calculation and experimental results show that the most unfavorable point for appearance of the rectangular steel cofferdam is in the steel sheet pile and especially the weakest position is at the corner of two sides of steel sheet pile cofferdam . Strengthen the cofferdam corner support is the problem that should be noted in the construction of the steel cofferdam.

References

[1] Wissmann K, Sheet pile tensions in cellular structures, Journal of Geotechnical and Geoenviromental Engineering. 129 (2003) 224-233.

[2] Stuart D M, Project-specific steel sheet piling applications, Practice Periodical on Structural *Design and Construction*. 9 (2004) 194-201.

[3] Crawford R J, A numerical model for predicting the bending strength of Larssen steel sheet piles, Journal of Constructional Steel Research. 58 (2002) 1361-1374.

[4] Kort D A, The transfer matrix method applied to steel sheet pile walls. International Journal for Numerical and Analytical Methods in Geomechanics. 27 (2003) 453-472.

[5] *Luo Guanyong, Cao Hong, Pan Hong, etc, Xinguang Bridge pier steel sheet pile cofferdam design* optimization and monitoring. Journal of South China University of Technology. 34 (2006) 124-129.