

ANALYSIS ON INTERACTION BETWEEN BLOCK OF WATER AND VERTICAL LARGE SPAN GATE

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Abstract: *Fluid Structure Interaction (FSI) is one of the emerging areas of numerical simulation and calculation that many researchers pay more attention in recent years. In general, although a considerable number of FSI studies exist, the numerical prediction of free surface cause tidal in the fields of fluid to gate is challenging. One of the main difficulties in a numerical method for this simulation is the modeling the interaction between fluid and gate where the dynamic response can transfer nature on gate to obtain the dynamic response of gate such deflection and stress during tidal propagation. The analysis is completed in 3D with a help of commercial ADINA-FSI softwave (Bathe. K.J, 2012) in which 3D modal is similar to structure of Muong Chuoi project with the main pipe truss seat on the side of the sea. The dynamic response impact on gate is based on the tidal wave characteristic in Mekong delta river.*

Keywords: FSI, tidal wave, vertical large span gate, one-way coupling, two-way coupling.

1. INTRODUCTION

At present, almost all the guidance for designed steel gates are mainly based on China standard, American standard and Eurocode standard. The assessment of dynamic response of gate in tidal region is very seldom. Especially, the new typical of gate applies to the practice for the first time and there is not a uniform standard for the dynamic design of gate structure so far. In comparison to the small or average span, the gate has large span gain more and more effective of dynamic response which the traditional static method cannot simulate accurately. Therefore, the topic study on fluid and gate interaction plays an important role for designing or checking the gate safety operation in special tidal region in Vietnam. Since several remarks have identified in this research, a general recommendation to investigate the dynamic response designs of the gate should be considered in the design standard for tidal region of Vietnam.

The approach of fluid-gate interaction is expensive and time-consuming for a detailed description of the interaction between the flow and gate structure. There are still some problems which have not been solved satisfactorily. Therefore, it is still necessary to enter into in-depth discussion and research on the issue in order to make a scientific and reasonable evaluation of the fluid-structure coupling system of fluid and gate more comprehensively and accurately. This research topic of fluid and structure interaction analysis on vertical large span gate in tidal region of Vietnam is simulated and expected the research on fluid and gate interaction have conducted by the method of one-way (OWC) and two-way (TWC) (Dohmen. HJ, 2011) that allow the tidal wave propagation can automatically generate and act directly on gate to obtain the dynamic responses of gate.

An overview diagram of the components that have been considered in further analyses and the interaction between fluid and structure are shown in Figure 1. This project has been approached by using the method of FSI (Chessa.J, 2006) to

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investigate and quantify the differences in the stress or deformation produced in each member of the gate between OWC fluid-solid coupling & TWC fluid-solid coupling methods.

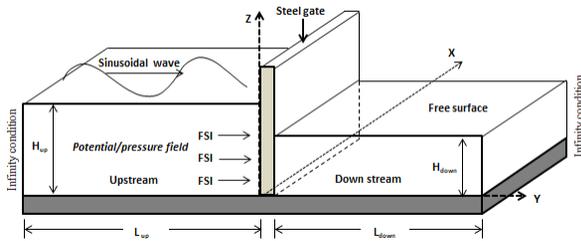


Figure 1. Vertical model space representing the dynamic domain that influences each other through interaction solution: Fluid and Gate. The sluice is considered infinity long and the boundary condition for flow domain when described by potential flow has been included.

The numerical analytical method requires several geometrical simplifications. The following statements are considered in order to reduce computational efforts, time and also to achieve reasonable conclusions from the project.

- In the flow domain, bottom surface is seam be flat, the sediment movement was almost negligible.
- The structure is considered to be fixed supports on left and right by slot of sluice, simple support at bottom by floor.
- The effect of structural damping does not include in the structural model and the effect of pressure float is neglected altogether.

2. METHOD OF FSI

Fluid-Structure coupling is a complex interdisciplinary problem involving solid mechanics, fluid mechanics, computational mechanics, mathematical principle, fluid dynamics, and includes many different fields of application, such as aerospace, marine, bioengineering, earthquake geology engineering, water conservancy and civil engineering.

The difficult problem in the analysis on fluid-structure interaction comes from the coordination of free surface of fluid and solid. The coordinate system mainly used in describing fluid and solid are not uniform, which leads to the failure of the whole coupling calculation. In order to solve the above problems, first proposed the ALE (Arbitrary Lagrangian-Eulerian) method (Aesden. AA, 1974) for flow field calculation and analysis by coupled Eulerian-Lagrangian concept. Then the ALE method was introduced into the finite element method, and began to develop gradually. The ALE method unifies the Lagrangian and Eulerian two coordinate systems and overcomes their shortcomings, and has been widely used to deal with fluid-structure coupling interface problem, fluid free surface problem and large deformation problem of solids. The fluid-Structure interaction can be divided into OWC (One Way Coupling) fluid-structure coupling and TWC (Two Way Coupling) fluid-solid coupling in the direction of data flow.

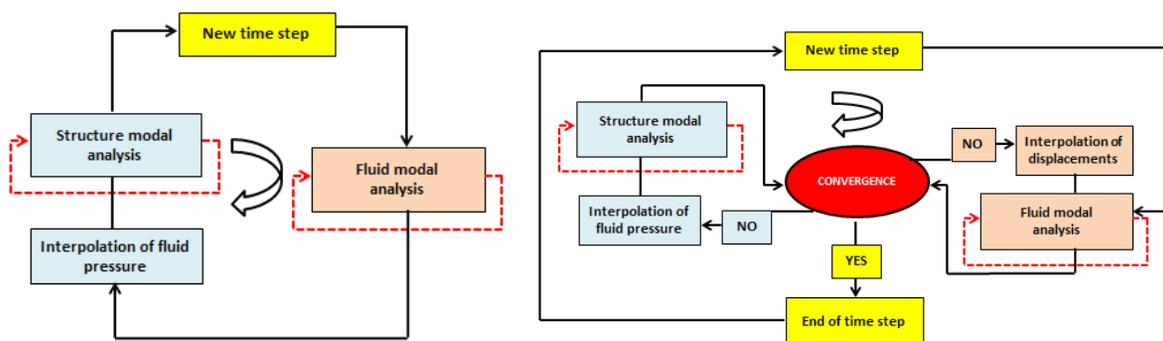


Figure 2. Left: One-way coupling method; Right: Two-way coupling method.

OWC fluid-solid coupling is generally applied to the movement of fluids, although it affects the deformation of the solid structure but the deformation of the solid structure is relatively small, thus the influence of the deformation convection field can be neglected. The TWC fluid-solid coupling is mainly suitable for the deformation of solids due to the movement of fluids, so that the influence of the deformation convection field of solids cannot be neglected. Which in turn triggers the redistribution of the flow field, the TWC fluid-solid coupling problem is more complicated than the OWC fluid-solid coupling problem. Therefore, the calculation method of OWC fluid-solid coupling is generally used in solving many engineering fluid-solid coupling problems, but for those problems of fluid-solid coupling which need to consider vibration and deformation, the TWC fluid-solid coupling problem is obviously more accurate.

Regardless of whether one-way (OWC) or two-way (TWC) coupling methods are used, the solutions are based on a partitioned method where separate solutions for the different physical fields are prepared. One field that has to be solved is fluid dynamics, the other is structure dynamics. At the boundary between fluids and steel gate structure, the fluid-structure interface, information for the solution is shared between the fluid analysis and structure analysis.

Model gate in multidimensional

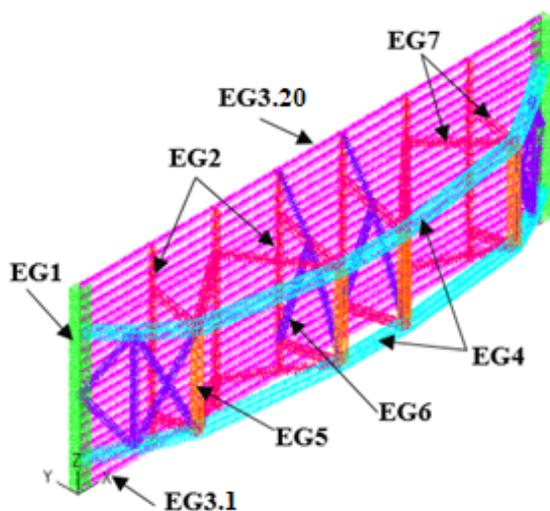


Figure 3. Define beam elements properties

3. APPLICATION

3.1. Model of flow

Large Eddy Simulation (LES) Model

LES Model of incompressible flow ($\rho=1000\text{kg/m}^3$, $\mu=0.001\text{Pa}\cdot\text{s}$). The computational domain is divided into upstream and downstream. The flow modal of upstream at open channel in the coupling system is a box of dimensions $[L=100\text{m}\times H=10.5\text{m}\times B=40\text{m}]$ discretized with a fully structured fine mesh of 252000 element. In order to analyze the fine mesh at final channel with the number of subdivisions of mesh $L:H:B=150:42:40$; The initial velocity field $u=1\text{m/s}$ has been applied at the open channel and tidal wave sinusoidal shape is naturally generated along upstream and act on structure. At downstream, the bock of standing water in 8m depth is replaced simply by the adding load on the surface of gate and is deflected gather to gate in coupling system during tidal propagation.

3.2. Model of Structure

Modal structure of gate in 40m large and 15m high dimensional is define in Figure, beam element is modeled as a 2-nodal Hermitian beam.

Section properties (Element type/Material)

EG1: Tube beam / [M1]

EG2: Vertical beam / [M1]

EG3: Horizontal beam / [M1]

EG4: Two main curve pipe beam / [M2]

The truss pipe structure

EG5; EG6; EG7: Pipe beam / [M2]

EG8: Thickness and material water retaining front: 10mm / [M1].

A linear elastic

Density: $7800(\text{kg} / \text{m}^3)$

Elastic Modulus: $2 \cdot 10^{11}(\text{N} / \text{m}^2)$

The Possion's ratio: 0.3

Table 1. Material properties

Bound	S235 (EN 10025-2) [M1]	C35E (EN10297-1:2003) [M2]
	-MPa-	-MPa-
f_y	225	380
f_t	360	600
f_s	228	320
E_c	2.10^5	2.10^5

f_y – Yield strength; f_t – Tensile strength; f_s – Shear strength
EG1, 2, 3, 4, EG8: S235 (EN 10025-2); EG5, 6, 7: C35E (EN10297-1:2003)

In order to calculate the compressive and tensile along beam element, the properties cross section of each element group along X-direction

(perpendicular to flow direction) and Y-direction (flow direction) is found in Table 2 to Table 4, respectively.

Table 2. The properties of cross section of element beam with Y- direction

Element group	Area $A (m^2)$	Moment of inertia $I (m^4)$	Bending modulus $W(m^3)$	Shearing modulus $S(m^3)$	Width of shear section $b(m)$
EG1	0.05940876	0.010705279	0.019464144	0.011430555	0.0318
EG2	0.0127200	0.0006784	0.0016960	0.0012720	0.0159
EG3	0.012908	0.000276169	0.001578111	0.000887047	0.014

Table 3. The properties of cross section of element beam with X- direction

Element group	Area $A (m^2)$	Moment of inertia $I (m^4)$	Bending modulus $W(m^3)$	Shearing modulus $S(m^3)$	Width of shear section $b(m)$
EG1	0.05940876	0.006578623	0.016446557	0.009202726	0.0318
EG2	0.0127200	0.0000003	0.0000337	0.0000253	0.8
EG3	0.012908	0.000123063	0.000615497	0.000559672	0.028

Table 4. The properties of cross section of pipe beam element

Element group	Area $A (m^2)$	Moment of inertia $I (m^4)$	Bending modulus $W(m^3)$	Shearing modulus $S(m^3)$	Width of shear section $b(m)$
EG4	0.062548800	0.007759304	0.015766905	0.009921493	0.04
EG5	0.040031232	0.003178211	0.005166499	0.005079805	0.032
EG6	0.028415744	0.001484825	0.001961158	0.002925288	0.028
EG7	0.019751573	0.000606085	0.000615783	0.001558137	0.0254

3.3. Boundary condition

The entire model gate contacts to bilateral water in coupling system based on definition

type of potential for flow in Table 5. Modal of gate is analyzed in case gate close to prevent tidal.

Table 5. Define potential interface boundary

Upstream		Downstream	
Part of domain	Type of potential	Part of domain	Type of potential
Top	Free surface	Top	Free surface
Bottom	wall	Bottom	wall
Both side	Sliding-wall	Both side	Sliding-wall
Right	Fluid-infinite Region	Left	Fluid-infinite Region
Left	Fluid-Structure	Right	Fluid-Structure

3.4. Time function

Time function following the shape of sinusoidal wave $t_i = \cos(2\pi t_i / T_n)$ is set up to model. The analysis is conducted in time step 0.005 for a period time $t = 20T_n$ to ensure stability and convergence where the period of vibration $T_n = 4s$.

4. RESULTS

4.1. Presenting wave propagation along channel

In order to get more accurate results, multidimensional model is generated in coupling system. The water level fluctuation in front of gate during tidal wave propagation along channel is shown in Figure illustrates the fluctuation and snapshot of free surface along channel over time meet the agreement of shape sinusoidal wave results from laboratory experiments of Chanson (Hubert Chanson, 2011).

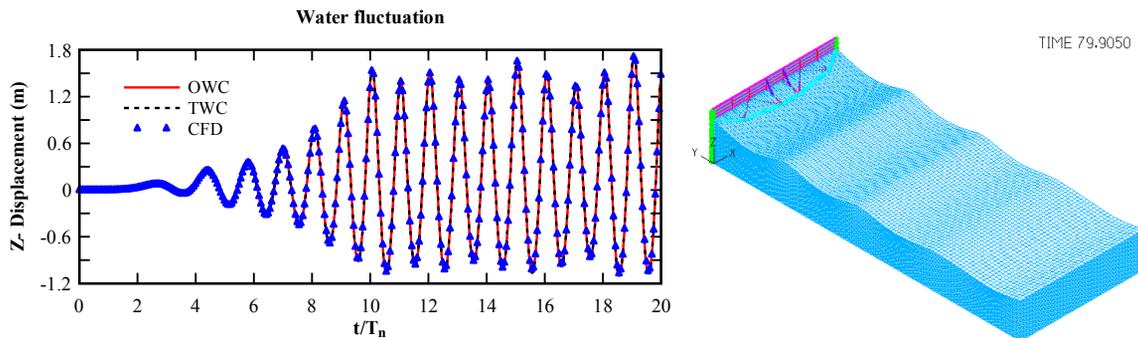


Figure 4. Water level fluctuation in front of gate during tidal wave propagation

4.2. Effective of tidal on displacement of gate

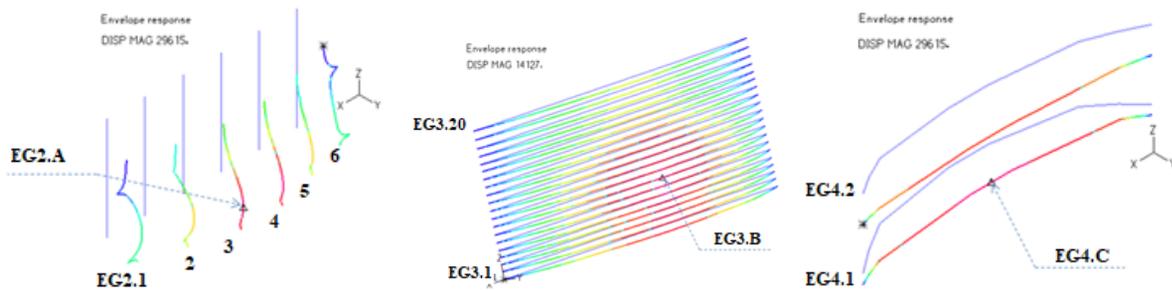
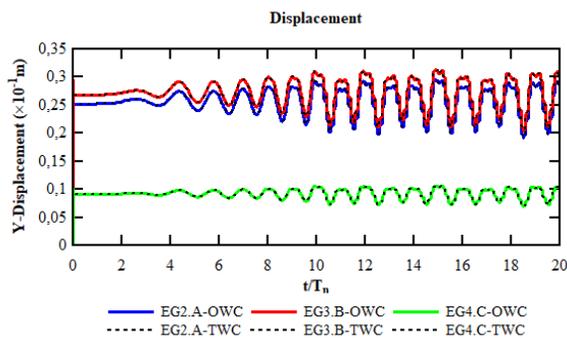


Figure 5. Shape displacement of EG2; EG3 and two main curve beams EG4



List	Method	Maximum Displacement
		Y. (mm)
EG2.	Static	24,9
	OWC	27,8(+11.65%)
	TWC	30,1(+20.88%)
EG3.	Static	26,7
	OWC	29,5(+10.49%)
	TWC	31,9(+19.48%)
EG4.	Static	8,90
	OWC	10,2(+13.97%)
	TWC	10,7(+19.55%)

Figure 6. Fluctuation of maximum/minimum displacement overtime at EG2.A, EG3.B and EG4.C in comparison two methods of coupling system OWC and TWC

Duration time of tidal fluctuation, the maximum displacement of gate is appeared on horizontal beam EG3.B with the ratio of largest displacement 0,0319 m to span dimension of gate 40m is 1/1254. The results shows that, the relative displacement of gate is smaller than that allowed number of 1/1000.

4.3. Effective of tidal on stress of gate

Based on the results of gate structure which obtained from coupling system, the increasing

percentage of stress is resulted from the comparison between coupling system method of OWC and TWC to static analysis. Results from Table 6 show that, TWC fluid-gate coupling system is obviously larger results. The stress concentrates on the main spatial structure of hollow pipe beam element up to 20%. As specially two main curve pipe beams although this element has a moment of inertia larger more 12 times than the smallest element but the increasing the stress is still large around 20%

Table 6. Compress and Tensile of pipe beam element along the Y/X-direction

List	Method	Tensile (+) and Compressive (-) Stresses σ (MPa) -Y direction-	Tensile (+) and Compressive (-) Stresses σ (Mpa) -X direction-
EG2	Static	31.93/-37.22	4/-9.29
	OWC	34.95/-40.85 (+9.46%/+9.74%)	4.51/-10.41 (+12.75%/+12.06%)
	TWC	38.69/-43.99 (+21.17%/+18.19%)	5.09/-10.39 (+27.25%/+11.84%)
EG3	Static	11.35/-11.99	41.29/-41.93
	OWC	12.67/-13.43 (+11.63%/+12.01%)	44.94/-45.71 (+8.84%/+9.02%)
	TWC	13.4/-14.17 (+18.06%/+18.18%)	48.9/-49.67 (+18.43%/+18.46%)
EG4	Static	22.49/-34.23	9.09/-11.1
	OWC	25.24/-38.7 (+12.23%/+13.06%)	10.25/-12.55 (+12.76%/+13.06%)
	TWC	26.39/-40.3 (+17.34%/+17.73%)	10.9/-13.28 (+19.91%/+19.64%)

5. CONCLUSION

This paper proposed the fluid and structure interaction analysis on vertical large span gate in the

tidal region of Vietnam. The influence of tidal wave to gate through new method of assigning dynamic load based on fluid structure interaction is studied in

detail. According to the merits of the research, the main research contents are summarized as follows

(1) The tidal wave propagation along open channel flow upstream of gate is analyzed by computational fluid dynamics simulation. The wave properties such as wave amplitude and wave length are driven by the velocity distribution and the period vibration which assign in the time history analysis at open channel.

(2) The numerical coupling (FSI) analysis have been analyzed using the method of OWC and TWC to be performed in a reasonable time frame for obtaining the hydrodynamic pressure of flow

and the dynamic response of gate during tidal propagation. The influence of tidal wave on gate is not smaller and should be a suggestion for the analysis in tidal region of Vietnam.

(3) The large cycle stress and displacement are concentrated in joint point where connect to hollow pipe beams of spatial structure. In general, this location also there is much welding residual stress and the stress concentration in the joint point, which is harmful to the fatigue of the structure. This study can keep continuous research in which it is warning to fatigue strength problem for safety operation of gate.

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Tóm tắt:

PHÂN TÍCH TƯƠNG TÁC GIỮA KHỐI NƯỚC TRƯỚC VAN VÀ CỬA VAN PHẪNG NHỊP LỚN BẰNG PHƯƠNG PHÁP FSI

Nghiên cứu tương tác giữa khối nước và kết cấu công trình (FSI) là một trong những lĩnh vực nghiên cứu mới của mô phỏng và tính toán số được nhiều nhà nghiên cứu trên thế giới chú ý hơn trong những năm gần đây. Bài báo sử dụng phương pháp FSI để nghiên cứu phân tích tương tác khối nước trước van có kể đến tác động của sóng triều hình sin tác động trực tiếp lên cửa van phẳng khẩu độ lớn là công ngăn triều khu vực đồng bằng sông Cửu Long. Từ đó phân tích, đánh giá được ảnh hưởng của dao động sóng hình sin trước cửa van đến biến dạng và ứng suất của cửa van trong quá trình làm việc. Các kết quả nghiên cứu được thực hiện trên mô hình không gian dựa trên hình dạng tương tự tham khảo từ kết cấu cửa van Mương chuối với hệ giàn không gian được bố trí về phía biển. Số liệu đặc trưng sóng của sóng thuộc khu vực đồng bằng sông Cửu Long với sự trợ giúp của phần mềm ADINA-FSI.

Từ khóa: FSI, sóng triều hình sin, cửa van phẳng, tương tác một chiều, tương tác hai chiều.

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