Report of the 2nd Workshop of ISOPE Numerical Wave Tank Group Benchmark Test Cases of Radiation Problem, (Brest, May 1999)

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INTRODUCTION

Introduction of NWT group and its brief history

The Numerical Wave Tank (NWT) group of the International Society of Offshore and Polar Engineers was established at the 5th ISOPE conference in The Hague (1995) by Prof. C.H. Kim (Texas A & M University). This group is open freely to everybody interested in this topic. It is aimed at developing links between active researchers in the field of the numerical simulation of free surface waves, their generation and their interaction with solid bodies. The activities of the group will tend to:

- Prompt the concept of numerical wave tank in the scientific community,
- Exchange experience between participants in a friendly spirit, exempt from competition attitude,
- Build and maintain a free access data bank on selected benchmarks.

At the 6th ISOPE conference in Los Angeles (1996), A.H. Clément was elected by the participants as the group leader. It was also decided that the mandate of group leader is two years.

During the NWT group meeting at the 7th conference in Honolulu (1997), the concept of Numerical Wave Tank was clarified by the participants. Numerical Wave Tanks are computer codes whose final goal is to reproduce physical wave basins as closely as possible. They must present at least the following features :

- free surface flow dominated by gravity in a bounded domain,
- fully non-linear boundary conditions (free-surface, floating body)
- simulation in the time-domain
- physical wave generation (moving wall or varying pressure)
- finite constant depth

Extra properties may possibly be accounted for as for instance: viscosity, surface tension, sediment transport, wave breaking, current, uneven bottom, sloping beaches, fixed bodies, floating bodies, other modes of generation,..... At this 1997 session, it was also decided by the members of the group to begin a series of informal workshops meeting where computational benchmark cases will be defined and their results discussed and commented in a special session during the forthcoming ISOPE conference.

The first NWT workshop was held at the 8th ISOPE conference in Montréal (1998) chaired by the group leader A.H. Clément and Prof. Naito (Osaka University). Topic of the first benchmark test was numerical wave absorption. The results of benchmark test of each participants were gathered, analyzed and presented by the group leader. In the free discussion, the future topics of the benchmark were proposed by the participants.

- Spectral bandwidth of NWTs,
- Numerical instabilities,
- Propagation of solitary waves,
- Comparison with experiments,
- Wave body interaction.

At the end of the workshop, K. Tanizawa was elected as the next group leader and A.H. Clément undertook the subleader. The detail of the 1st NWT workshop was reported by A.H. Clément (1999).

The second NWT Workshop was held at ISOPE conference in Brest (1999). The results, gathered and analyzed were presented by the group leader then openly discussed by all the present participants (contributing or not). The topic of the 2nd benchmark was wave radiation force, which is classified into wave body interaction problem, one of the proposed topic in the last workshop.

Free access data bank of benchmarks

The submitted benchmark results from the contributors are analyzed and stored in the NWT data banks. These data banks are permanent and accessible freely via Internet. The data bank of the 1st workshop is provisionally in ftp site

ftp://ftp.ec-nantes.fr/NWT/1998/

and the data bank of the 2nd workshop is provisionally in web site

http://www.srimot.go.jp/dyn/member/tanizawa /nwtws1999/index.htm

These sites will be integrated into ISOPE web site and progressively enriched with the numerical results of the participants. Then everybody can get the participant's data files and perform his own analysis and comparisons. The files contain not only numerical results, but also a short text section where the numerical technique is summarized and related bibliographic references are listed. It was confirmed at the 2nd NWT workshop that this benchmark is permanent, with no deadline at all. Therefore contributors can send their files even after the corresponding workshop. The files will be processed and then put in the data bank to enrich it for future users.

BENCHMARK TEST OF RADIATION FORCE

Numerical wave tanks (NWT) are expected to substitute or at least to supplement real wave tanks in near future. They can be applied to variety of simulations like fully nonlinear free-surface waves, wave radiation by forced oscillated body (radiation problem), wave and fixed body interaction (diffraction problem) and floating body dynamics (radiation and diffraction problem). To apply NWT to the design of ships and ocean structures, simulated hydrodynamic forces must be accurate and reliable.
The topic of the second workshop was radiation force computation by numerical wave tanks. In this benchmark test, hydrodynamic force acting on sinusoidal heaving wedge is mainly considered. Fourier analysis was applied to the simulated time series of heaving force and nonlinear components of heaving force were compared up to third order. Pressure computation on the heaving wedge was the key point of this benchmark test.

Description of benchmark test

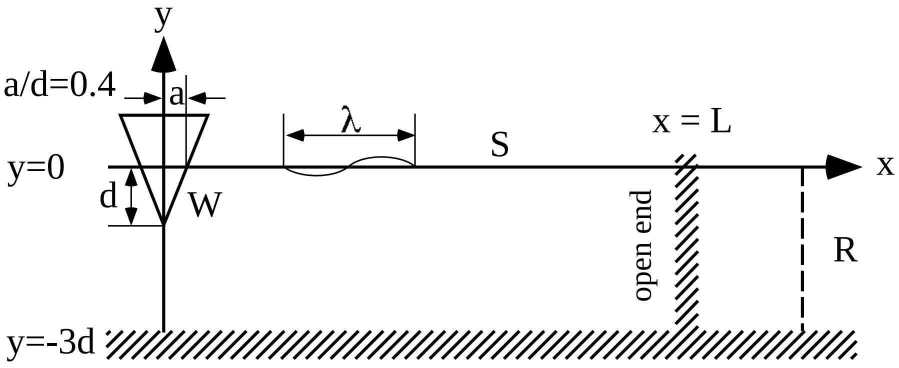

Figure 1 Sketch of 2D NWT for this benchmark test

- Left end ($x = 0$) is the axis of symmetry
- Right end ($x = L$) is supposed to be open
- Depth of wave tank : $h = 3d$
- Length of wave tank : $L \geq 4\lambda$
- Ratio between half breadth and depth of the wedge : $a/d = 0.4$
- Heave motion of the wedge : $Y = A \sin \omega t$
- Heave amplitude : $A/a = 0.2, 0.4, 0.6$
- Heave frequencies ω, periods T and corresponding wave length λ are given in Table.1.

Table 1 Nondimensional frequency, period and wave length

$\omega^2 a/g$	0.2	0.4	0.6	0.8	1.0	1.2
$T/\sqrt{a/g}$	14.049	9.935	8.112	7.025	6.283	5.736
λ/a	29.058	15.630	10.469	7.854	6.283	5.236

The numerical simulation is started from the calm condition at time $t = 0$, and should be continued until the wave field is converged to the periodically steady state. Any type of gradual start sequence of wedge motion and any type of numerical wave absorption method can be used at open end. The absorption of wave will begin at $x = L$ and may extend beyond this limit. If a numerical beach is used, it must begin at $x = L$ and extend further. R is the right boundary of the computational domain; it must located such that : $X_R \geq L$

Contributors

We had seven contributors listed in table 2. Seven of five use boundary element method, and the other two use finite element method and finite volume method respectively. In the following report, simulation methods used by contributors are referred as BEM-A ∼ BEM-E, FEM and FVM.

Table 2 List of contributors

Contributor	Simulation Method	Legend
K. Tanizawa	BEM Fully Nonlinear	BEM-A
M. Kashiwagi	BEM Fully Nonlinear	BEM-B
H. Kihara	BEM Fully Nonlinear	BEM-C
A.H. Clément	BEM Fully Nonlinear	BEM-D
C. Maisondieu	BEM 2nd order	BEM-E
R. Otto & J.H. Westhuis	FEM Fully Nonlinear	FEM
N. Hirata	FVM Fully Nonlinear	FVM

Benchmark test cases

The basic parameters of the benchmark test were heave amplitude ($A/a = 0.2, 0.4, 0.6$) and heave frequency ($\omega^2 a/g = 0.2, 0.4, 0.6, 0.8, 1.0, 1.2$). From the combination of these parameters, we had 18 test cases listed in table 3. The simulation method applied to the test cases is also listed in this table.

Table 3 Benchmark test cases and participants

$\omega^2 a/g$	0.2	0.4	0.6	0.8	1.0	1.2
A/a $= 0.2$	Case 1 BEM-A BEM-B BEM-C BEM-D BEM-E FEM FVM	Case 10 BEM-A BEM-B BEM-C BEM-E	Case 2 BEM-A BEM-B BEM-C BEM-D BEM-E FEM FVM	Case 11 BEM-A BEM-B BEM-C BEM-E	Case 3 BEM-A BEM-B BEM-C BEM-D BEM-E FEM FVM	Case 12 BEM-A BEM-B BEM-C BEM-E
A/a $= 0.4$	Case 4 BEM-A BEM-B BEM-C BEM-D BEM-E FEM FVM	Case 13 BEM-A BEM-B BEM-C BEM-E	Case 5 BEM-A BEM-B BEM-C BEM-D BEM-E FEM	Case 14 BEM-A BEM-B BEM-C BEM-E	Case 6 BEM-A BEM-B BEM-C BEM-D BEM-E FEM	Case 15 BEM-A BEM-B BEM-C BEM-E
A/a $= 0.6$	Case 7 BEM-A BEM-B BEM-C BEM-D BEM-E FEM	Case 16 BEM-A BEM-B BEM-C BEM-E	Case 8 BEM-A BEM-B BEM-C BEM-D BEM-E FEM	Case 17 BEM-A BEM-B BEM-C BEM-E	Case 9 BEM-A BEM-B BEM-C BEM-D BEM-E FEM	Case 18 BEM-A BEM-B BEM-C BEM-E

Case 1 ∼ Case 9 : Benchmark test cases,
Case 10 ∼ Case 18 : Options

Description of simulation methods

BEM-A

Name of contributor : Katsuji Tanizawa, Ship Research Institute, Japan

Simulation Method : Boundary Element Method (Linear Element), Fully nonlinear simulation based on MEL

Method for ϕ_t computation : Solving the boundary-value problem for ϕ_t
B.C. of ϕ_t on body surface : $\partial\phi_t/\partial n = n \cdot a + \partial\phi/\partial n \ \partial^2\phi/\partial s^2$

Wave absorption : Wave absorbing beach (beach length = wave length, Damping terms are added to kinematic and dynamic B.C.)

Intersection : Double nodes

Number of nodes : 20 per wave length, 21 on wedge

Time integral method : 4th order Runge-Kutta method, $\Delta t = T/20 \ T/40$

BEM-B

Name of contributor : Masashi Kashiwagi, Kyushu University - Research Institute for Applied Mechanics

Simulation Method : Boundary Element Method (Quadratic Element), Fully nonlinear simulation based on MEL

Method for ϕ_t computation : Solving the boundary-value problem for ϕ_t
B.C. of ϕ_t on body surface : $\partial\phi_t/\partial n = n \cdot a + \partial\phi/\partial n \ \partial^2\phi/\partial s^2$

Wave absorption : Wave absorbing beach (beach length = double wave length)

Intersection : Double nodes

Number of nodes : 20 30 per wave length, 21 on wedge

Time integral method : 4th order Runge-Kutta-Gill method , $\Delta t = T/25$ ($T/30$ for $A/a = 0.6$)

BEM-C

Name of contributor : Hajime Kihara, National Defense Academy, Japan

Simulation Method : Boundary Element Method (Quadratic Element), Fully nonlinear simulation based on MEL

Method for ϕ_t computation : Solving the boundary-value problem for ϕ_t
B.C. of ϕ_t on body surface : $\partial\phi_t/\partial n = n \cdot a + \partial\phi/\partial n \ \partial^2\phi/\partial s^2$

Wave absorption : Wave absorbing beach (beach length = wave length, Damping terms are added to kinematic and dynamic B.C.)

Intersection : Double nodes

Number of nodes : 18 per wave length, 11 on wedge

Time integral method : 4th order Runge-Kutta method , $\Delta t = T/20 \ T/160$

BEM-D

Name of contributor : Alain Clement, ECOLE CENTRALE DE NANTES

Simulation Method : Boundary Element Method (Linear Element), Fully nonlinear simulation based on MEL

Method for ϕ_t computation : Pressure is not computed locally. The time-derivative of the integral of the potential over the body, with the appropriate correction term to account for the change of the wetted surface in time.

Wave absorption : Coupled beach and active piston technique

Intersection : Double nodes

Number of nodes : 6 25 per wave length, 11 on wedge

Time integral method : 4th order Runge-Kutta method , $\Delta t = T/50$

BEM-E

Name of contributor : Christophe Maisondieu, IFREMER - Applied Hydrodynamics Laboratory

Simulation Method : Boundary Element Method, Boundary conditions developed to 2nd order

Method for ϕ_t computation : Derivatives of potential are directly given by resolution of integral equation. ϕ_t and other time derivatives are computed the same way.

Wave absorption : Wave absorbing beach (beach length = double wave length, Only used on free surface dynamic boundary condition.)

Intersection : The problem with singularities appear at both ends of the wedge could be solved by modification of normal directions at each extremity of the wedge. This option should be implemented soon.

Number of nodes : 60 per wave length, 31 on wedge

Time integral method : 4th order Runge-Kutta method , $\Delta t = T/60$

FEM

Name of contributor : Robert Otto & Jaap-Harm Westhuis, Twente University / MARIN

Simulation Method : Finite Element Method (Triangular elements with linear shape functions), Fully nonlinear simulation based on MEL

Method for ϕ_t computation : Solving the boundary-value problem for ϕ_t
B.C. of ϕ_t on body surface : $\partial\phi_t/\partial n = n \cdot a + \partial\phi/\partial n \ \partial^2\phi/\partial s^2$

Wave absorption : Numerical beach

Intersection : Velocity at Intersection Point is calculated from given ϕ_n and obtained ϕ_s on the wedge from the solution of the potential BVP.

Number of nodes : 20 30 per wave length, 4 27 on wedge

Time integral method : 5-step 4th order Runge-Kutta , $\Delta t = T/30$

FVM

Name of contributor : Nobuyuki Hirata, Ship Research Institute, Japan

Simulation Method : Finite Volume Method

- Governing equations : 2-D incompressible NS eqs. with artificial compressibility
- Discretization : Cell-centered finite volume method
- Convective terms : 3rd order upwind biased scheme based on Roe's scheme with MUSCL approach
- Viscous terms : 2nd order central differencing
- Solution procedure : Approximate Newton-relaxation approach with sGS method of linear system
- Free surface cond. : Nonlinear kinematic condition and zero stress condition.

Wave absorption : Wave absorbing beach (beach length = wave length, Damping terms are added to kinematic B.C.)

Number of nodes : 20 per wave length, 40 on wedge

Time integral method : 2nd order backward Euler formula , $\Delta t = T/540 \ T/700$

Body surface boundary condition of ϕ_t

Tanizawa (1996) gives fully nonlinear body surface boundary condition of ϕ_t as

$$\frac{\partial \phi_t}{\partial n} = \boldsymbol{N} \cdot \boldsymbol{\alpha} + q \ , \tag{1}$$

where $\boldsymbol{N}$ is the generalized unit normal vector of body surface

$$\boldsymbol{N} = (\boldsymbol{n}, \boldsymbol{r} \times \boldsymbol{n}) \ , \tag{2}$$

$\boldsymbol{\alpha}$ is the generalized acceleration of body

$$\boldsymbol{\alpha} = (\boldsymbol{a}, \dot{\boldsymbol{\omega}}) \tag{3}$$

and q is the normal acceleration of fluid due to flow on the body

$$\begin{aligned} q = {} & \boldsymbol{n} \cdot \boldsymbol{\omega} \times (\boldsymbol{\omega} \times \boldsymbol{r}) + \boldsymbol{n} \cdot 2\boldsymbol{\omega} \times (\nabla\phi - \boldsymbol{v} - \boldsymbol{\omega} \times \boldsymbol{r}) \\ & + k_n (\nabla\phi - \boldsymbol{v} - \boldsymbol{\omega} \times \boldsymbol{r})^2 + \frac{\partial \phi}{\partial n}\left(\frac{\partial^2 \phi}{\partial s^2}\right) - \frac{\partial \phi}{\partial s}\frac{\partial}{\partial s}\left(\frac{\partial \phi}{\partial n}\right) \end{aligned} \tag{4}$$

In the test cases, angular velocity and angular acceleration of the wedge is zero, $\dot{\boldsymbol{\omega}} = \boldsymbol{\omega} = 0$, curvature of body surface is zero, $k_n = 0$, and value of ϕ_n on the wedge surface is constant in space i.e. $\partial\phi_n/\partial s = 0$. Therefore, the body surface boundary condition of ϕ_t can be simply written as

$$\frac{\partial \phi_t}{\partial n} = n \cdot a + \frac{\partial \phi}{\partial n}\frac{\partial^2 \phi}{\partial s^2} \ . \tag{5}$$

This fully nonlinear body surface boundary condition is used to calculate pressure distribution on the body surface in BEM-A, BEM-B, BEM-C and FEM.

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RESULT OF BENCHMARK TEST

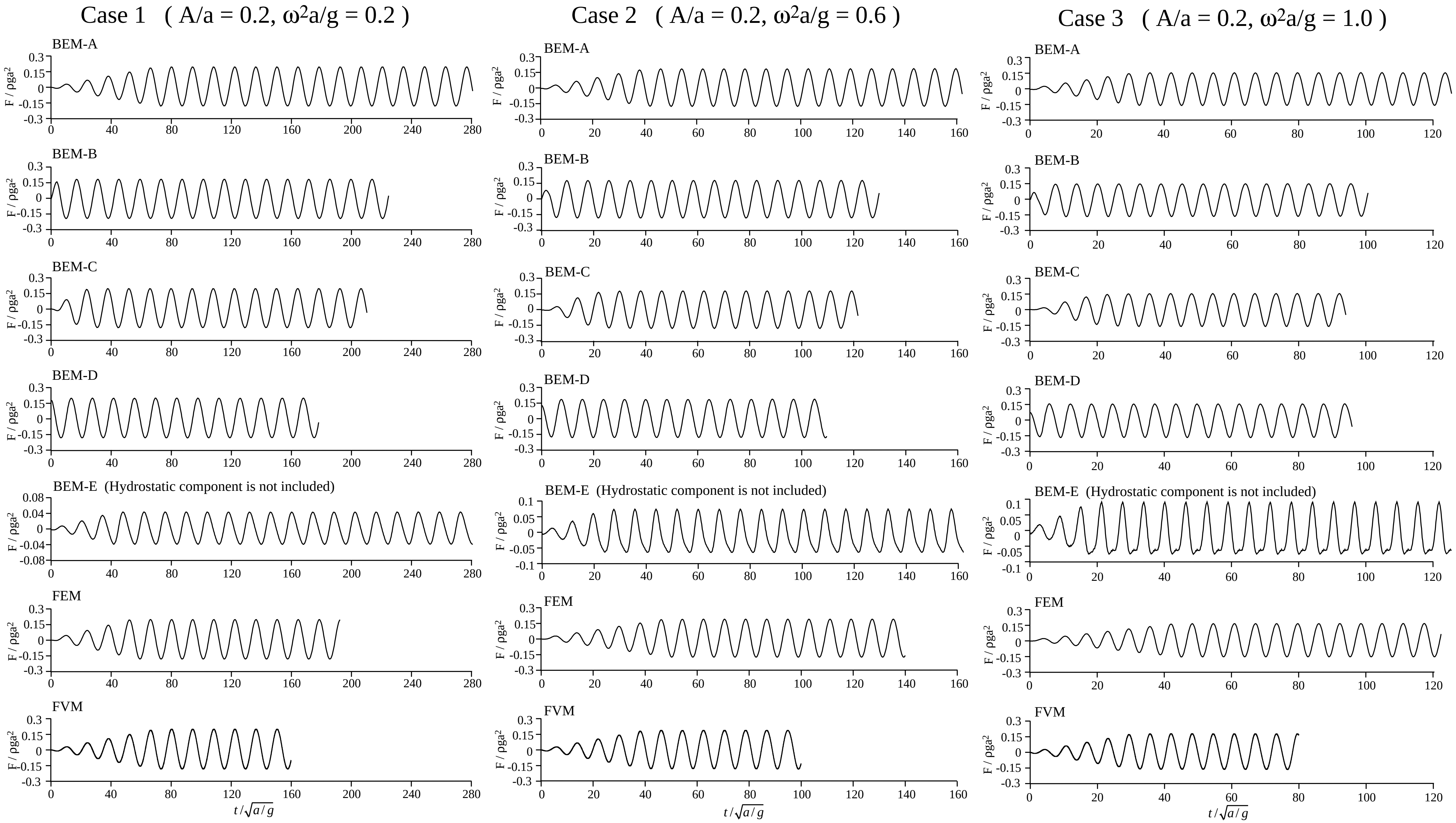
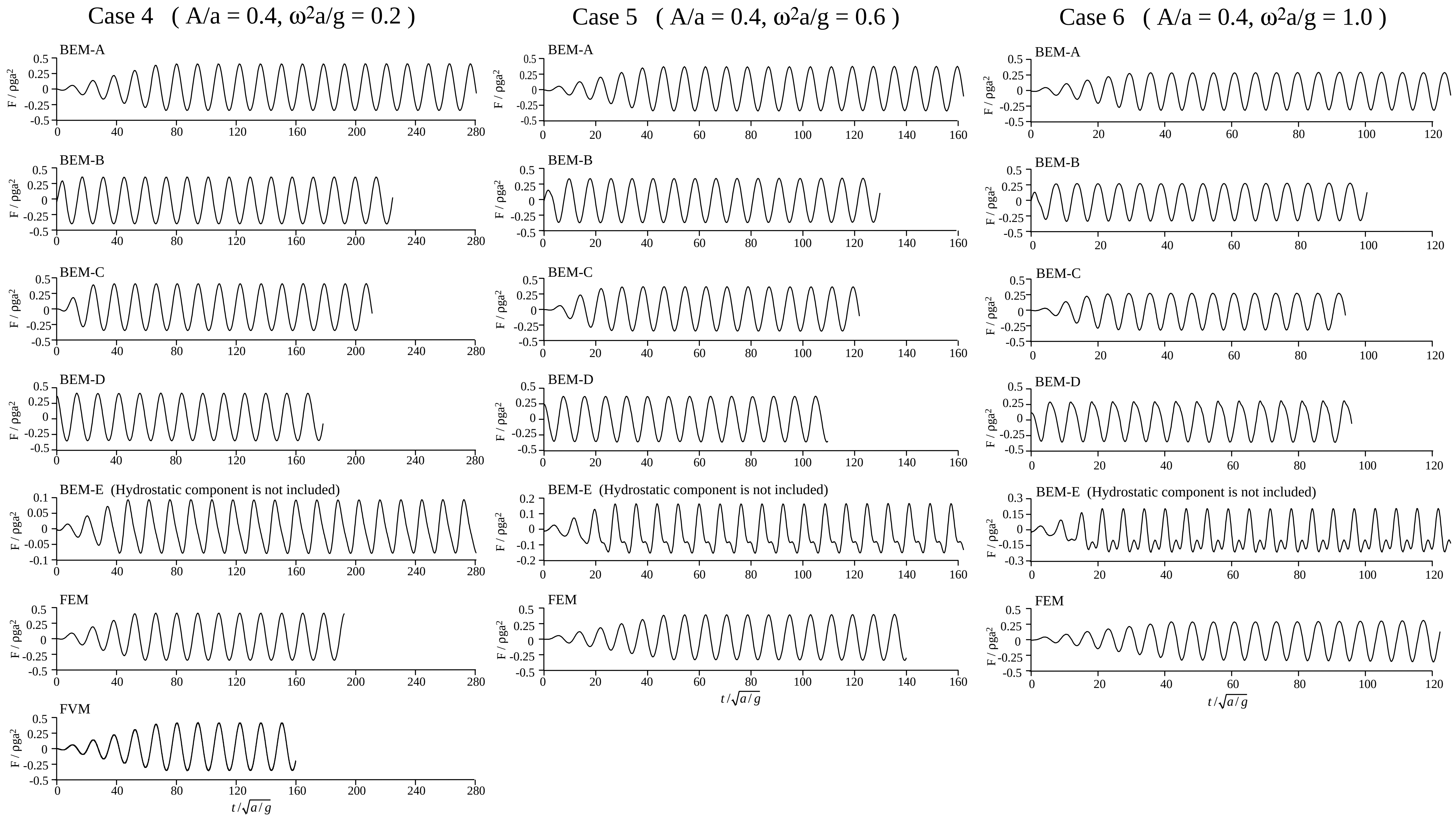


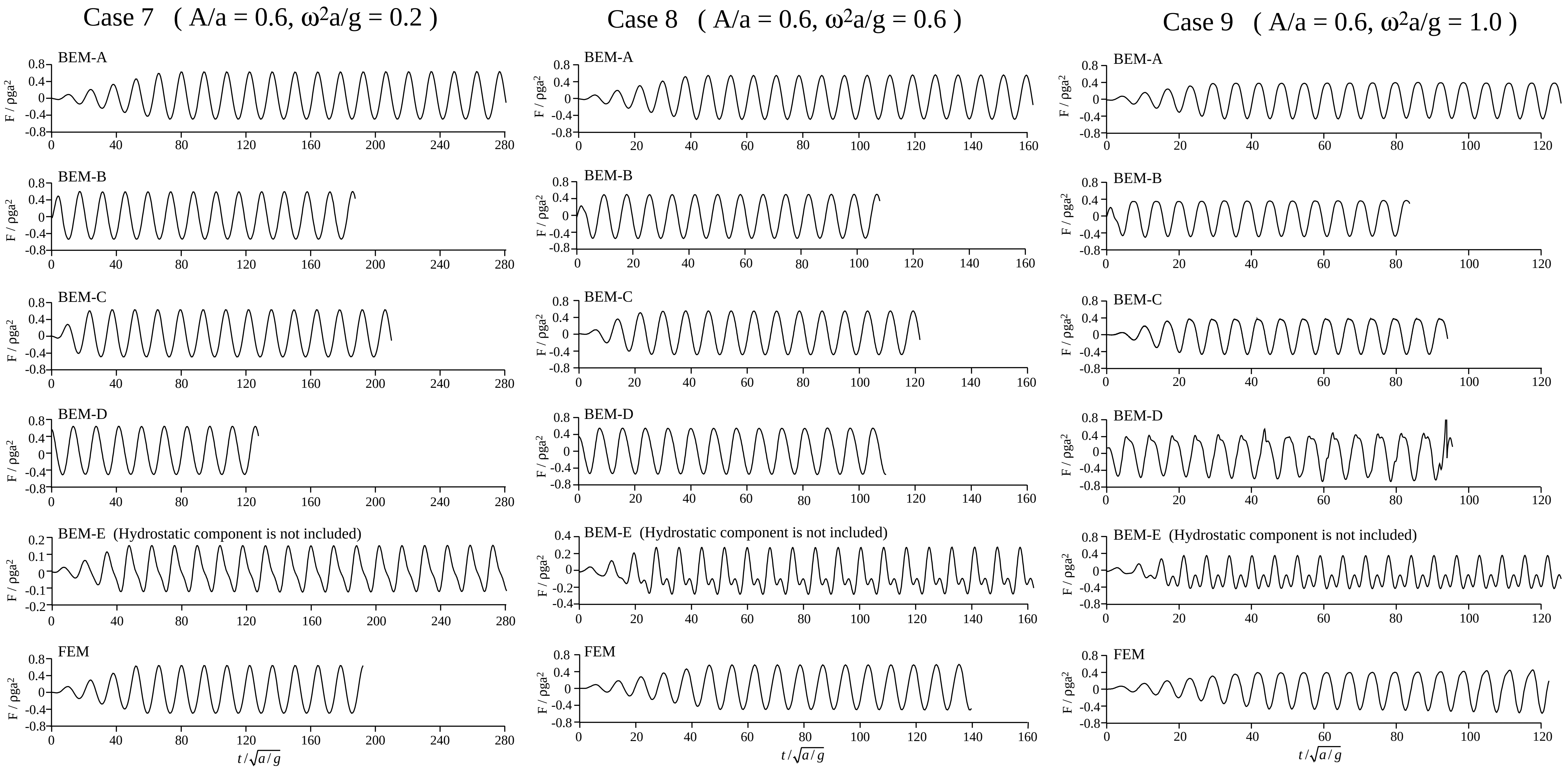
Figure 2-1 Simulated heave forces on the wedge


Case 4 (A/a = 0.4, $\omega^2 a/g = 0.2$)

Case 5 (A/a = 0.4, $\omega^2 a/g = 0.6$)

Case 6 (A/a = 0.4, $\omega^2 a/g = 1.0$)

Figure 2-2 Simulated heave forces on the wedge



Case 7 (A/a = 0.6, $\omega^2 a/g = 0.2$)

Case 8 (A/a = 0.6, $\omega^2 a/g = 0.6$)

Case 9 (A/a = 0.6, $\omega^2 a/g = 1.0$)

Figure 2-3 Simulated heave forces on the wedge

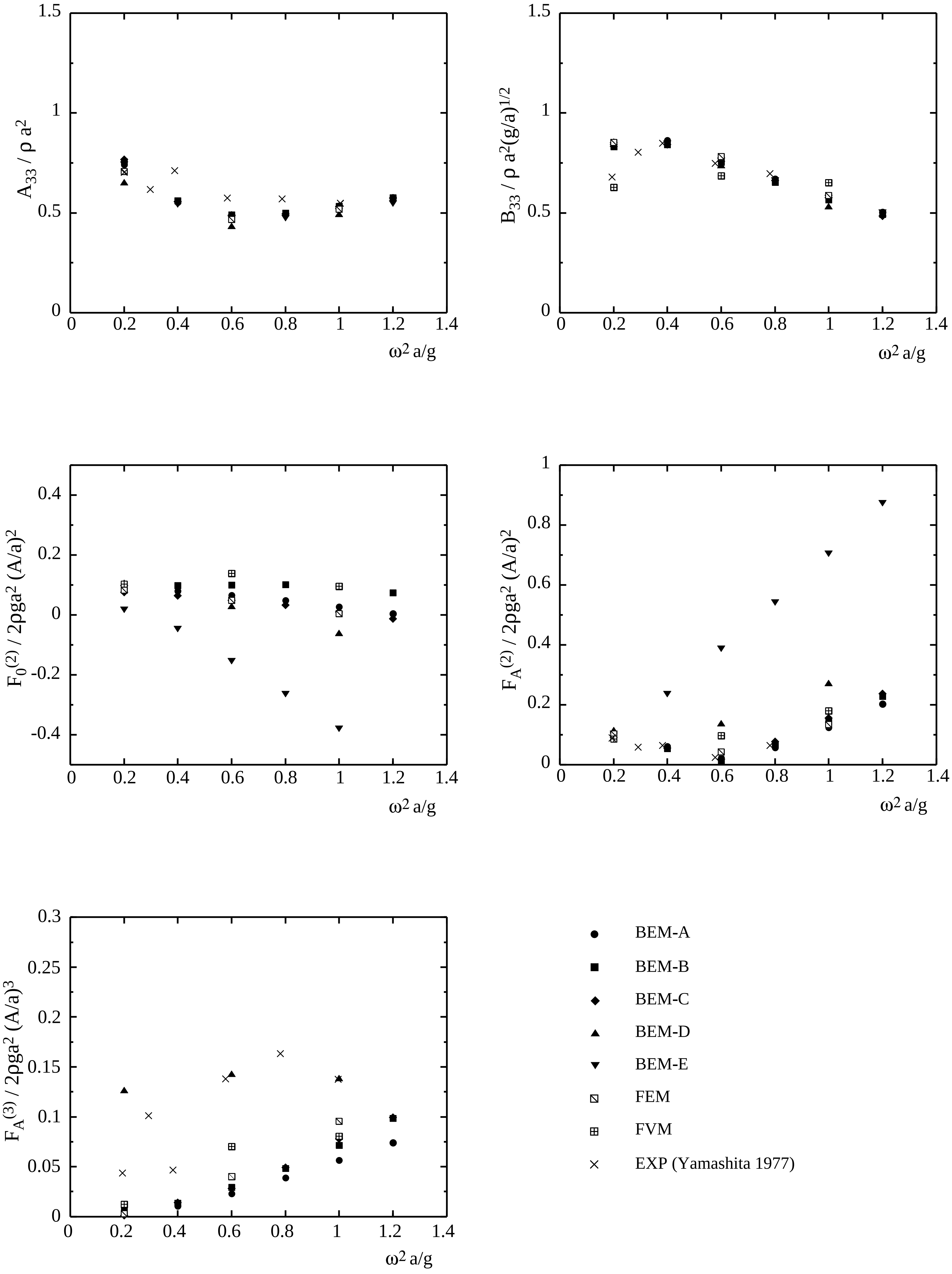


Figure 3-1 The first, second and third order components of simulated heave force ($A/a = 0.2$)

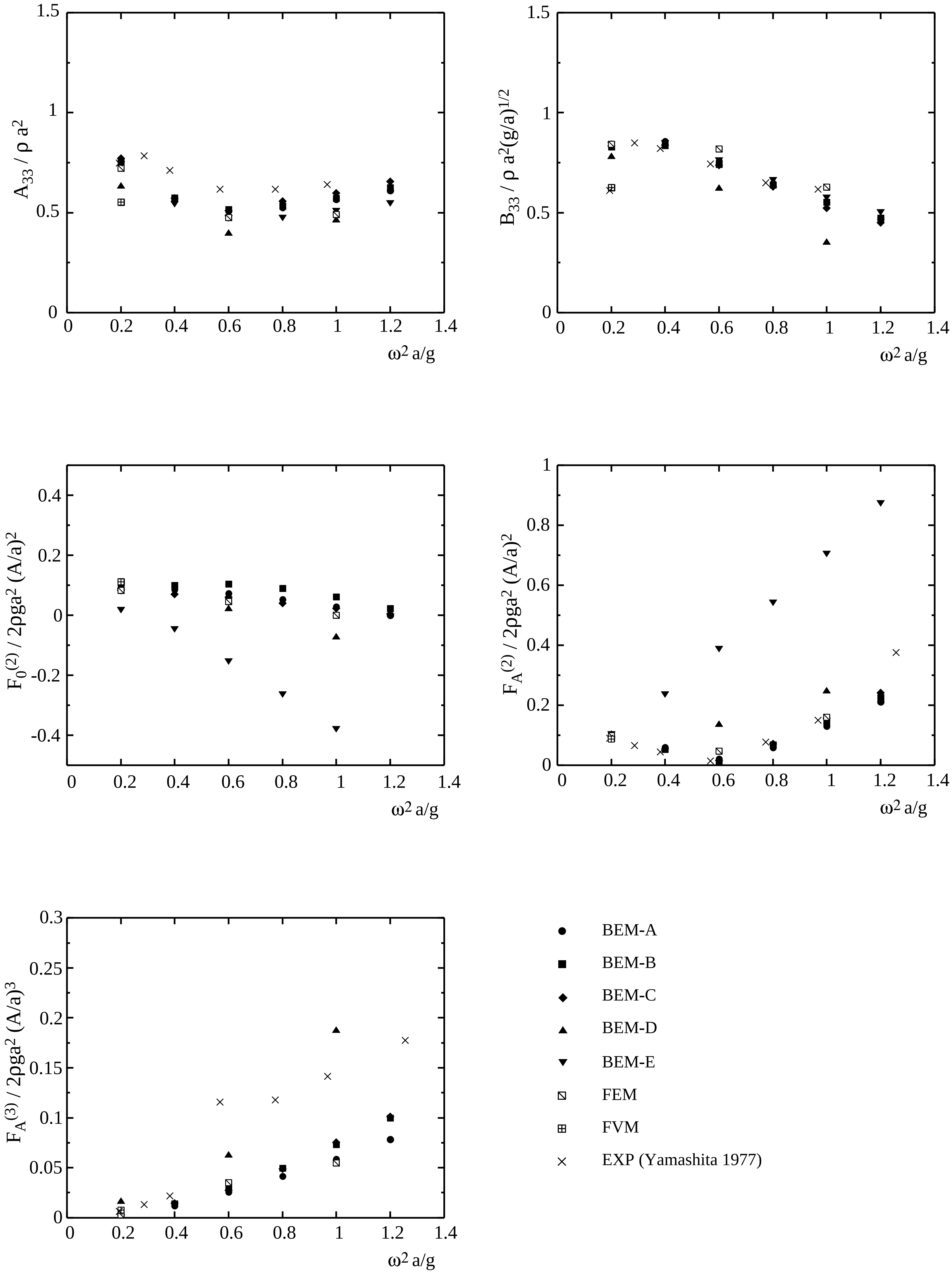


Figure 3-2 The first, second and third order components of simulated heave force ($A/a = 0.4$)

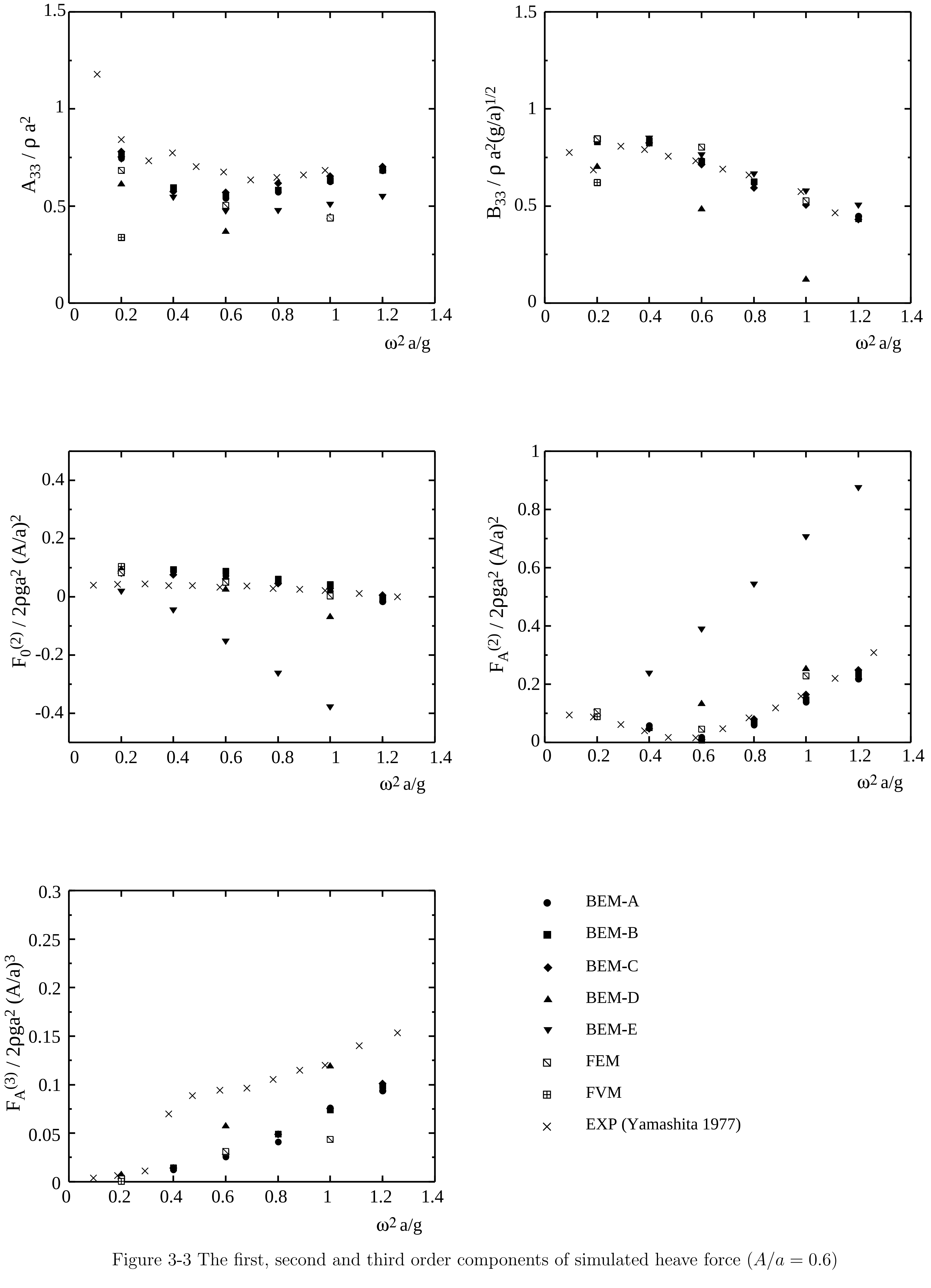


Figure 3-3 The first, second and third order components of simulated heave force ($A/a = 0.6$)