DYNAMIC TENSION ANALYSIS OF A SLACK MOORING FOR A FLOATING OFFSHORE WIND TURBINE

Pham Van PHUC*, Takeshi ISHIHARA**, Kenji SHIMADA*, Tetsuji SHIROEDA***

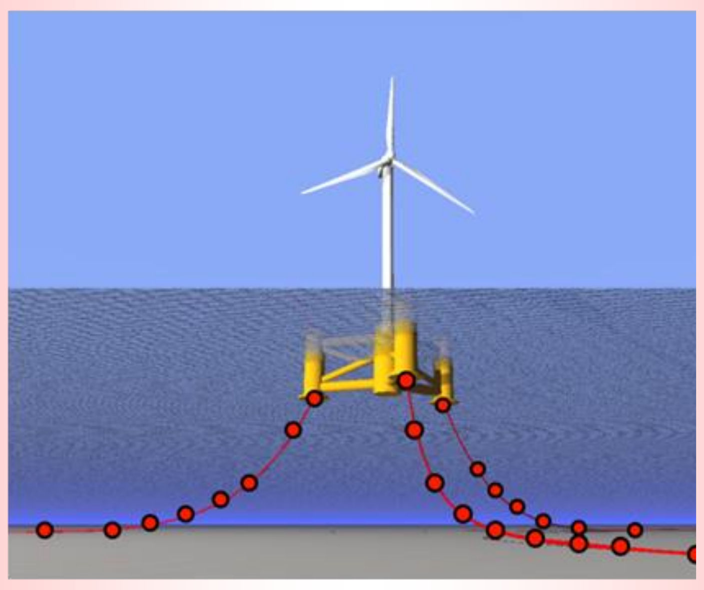
* Institute of Technology, Shimizu Corporation, 3-4-17 Etchujima, Koto, TOKYO 135-8530, JAPAN
** Department of Civil Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo, TOKYO 113-8656, JAPAN
*** Engineering headquarters, Shimizu Corporation, 2-16-1 Kyobashi, Chuo, TOKYO 104-8370, JAPAN

Objective

Mooring system plays an important role in the Floating Offshore Wind Turbine System (FOWTS) to keep its position from any critical weather conditions .

Existing design and most previous studies are only based on the linear mooring system without considering any slack and snap tensions that may cause some errors on the dynamic responses of FOWTS and damage the mooring system in storm conditions.

This study has developed a fully nonlinear mooring system using FEM method[1]. Some fundamental studies of cable in state of slack and snap tension, mooring cable in contact with the seabed in the experimental scale are described to understand the nonlinear behavior of mooring cable. Some comparisons with the previous studies are also presented to show the validity of the numerical method to evaluate impact tension.



A catenary mooring in FOWTS

Nonlinear FEM Method

■ Equation of motion

$$M\Delta\ddot{x} + C\Delta\dot{x} + K\Delta x = \Delta F$$

$$F = Q + F_g + F_b + F_h + F_c$$

where M is the mass matrix, C is the damping matrix and K is the nonlinear stiffness matrix of mooring cable system using truss element. The force F includes the internal force Q which is the function of tension of mooring cable, gravitational force F_g, buoyancy force F_b, hydrodynamic force F_h and seabed contact force F_c.

■ Hydrodynamic force

$$F_h = F_{hw} + F_{hM} + F_{hD}$$

$$F_{hw} = \rho_w C_M A\dot{u}$$

$$F_{hM} = -M_a\ddot{x} \quad ; \; M_a = \rho_w (C_M - 1)$$

$$F_{hD} = 0.5\rho_w C_D A(u - \dot{x})|u - \dot{x}|$$

where F_{hw} is the Froude-Krylov force, F_{hM} is the inertia force, F_{hD} is the drag force.

■ Seabed contact force

Frictional and normal force acting on the mooring elements in contact with the seabed using are modeled by the symmetrical stiffness matrix[3]. It is described in terms of a penalty constant stiffness k, and frictional coefficient μ with relative displacement of mooring element in tangential and normal directions.

$$F_c = \begin{bmatrix} \mu^2 k & 0 & \mu k \\ 0 & k & 0 \\ \mu k & 0 & k \end{bmatrix} x$$

Conclusion

・ This paper explained a nonlinear FEA using truss element which accounts for a frictional contact with seabed to simulate the dynamic response of the mooring line system.

・ Several fundamental studies and comparisons with previous studies are made to show the ability to simulate nonlinear behaviors of mooring line system.

・ Propose method showed very good agreement with the previous experimental results in comparison of the slack tension, snap tension and bottom interaction of slack mooring system.

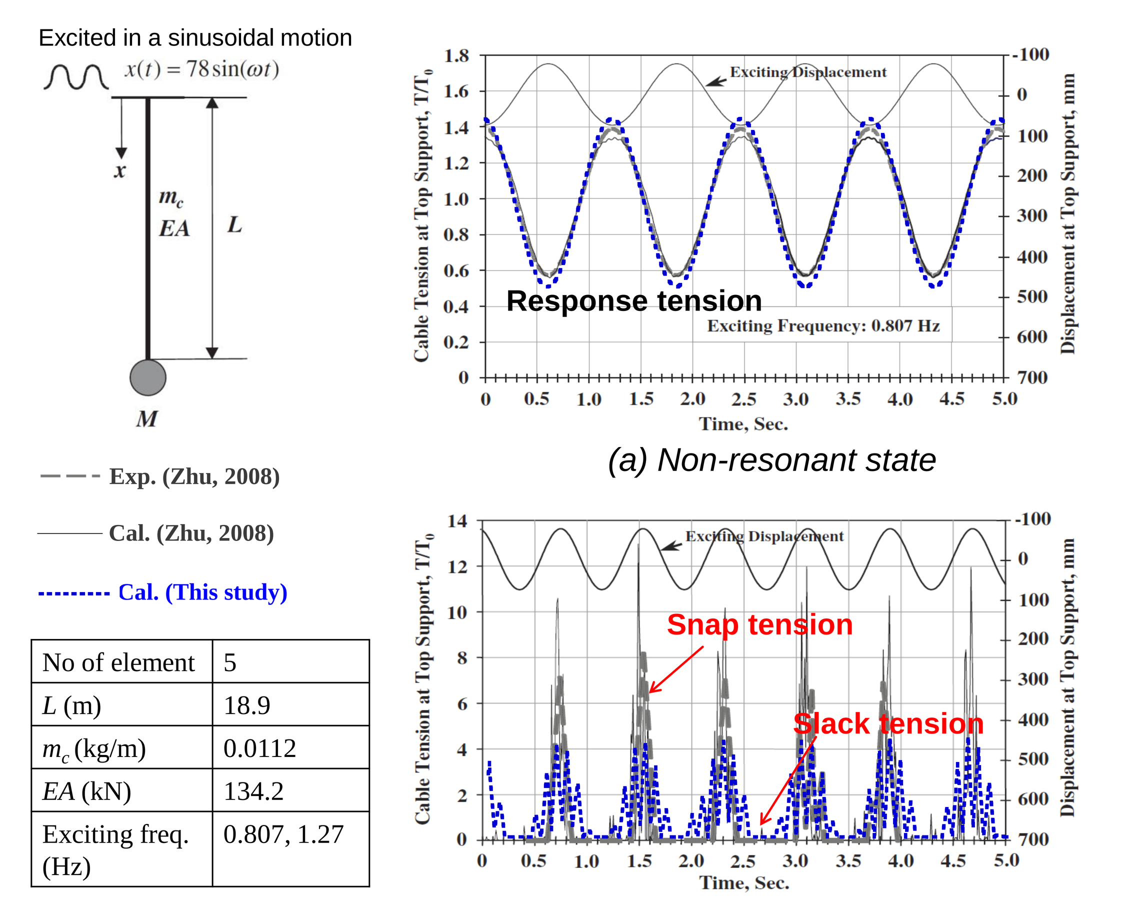
Reference

1. Phuc, P.V. and Ishihara, T., A study on the dynamic response of a semi-submersible floating offshore wind turbine system Part 2: Numerical simulation, Proc. of 12th international conference on wind engineering (ICWE12), 2007.
2. Gobat, J.I. and Grosenbaugh, M.A., Dynamics in the Touchdown Region of Catenary Moorings, Proc. of the Eleventh International Offshore and Polar Engineering Conference, 239-247, 2001.
3. Ju, S.H. and Rowlands, R.E., A Three-dimensional frictional contact element whose stiffness matrix is symmetric, J. of Applied Mechanics, 66(2), 460-467, 1999.
4. Zhu, Z.H., Dynamic modeling of cable system using a new nodal position finite element method, Communication in Numerical Methods in Engineering, 2008.
5. Fried, I., Large deformation static and dynamic finite element analysis of extensible cables, Computer & Structures, Vol.15, No.3, 315-319, 1982.
6. Koh, C.G., Zhang, Y. and Quek, S.T., Low-tension cable dynamics: Numerical and experimental studies, J. of Engineering Mechanics, Vol. 125, No. 3, 347-354, 1999.

Fundamental studies of Cable with Slack & Snap Tension

■ Submerged cable snapping in water

- An excited cable causes a large snap and slack tension in the resonant state.
- The simulated results show quite good agreement with previous studies of Zhu(2008)



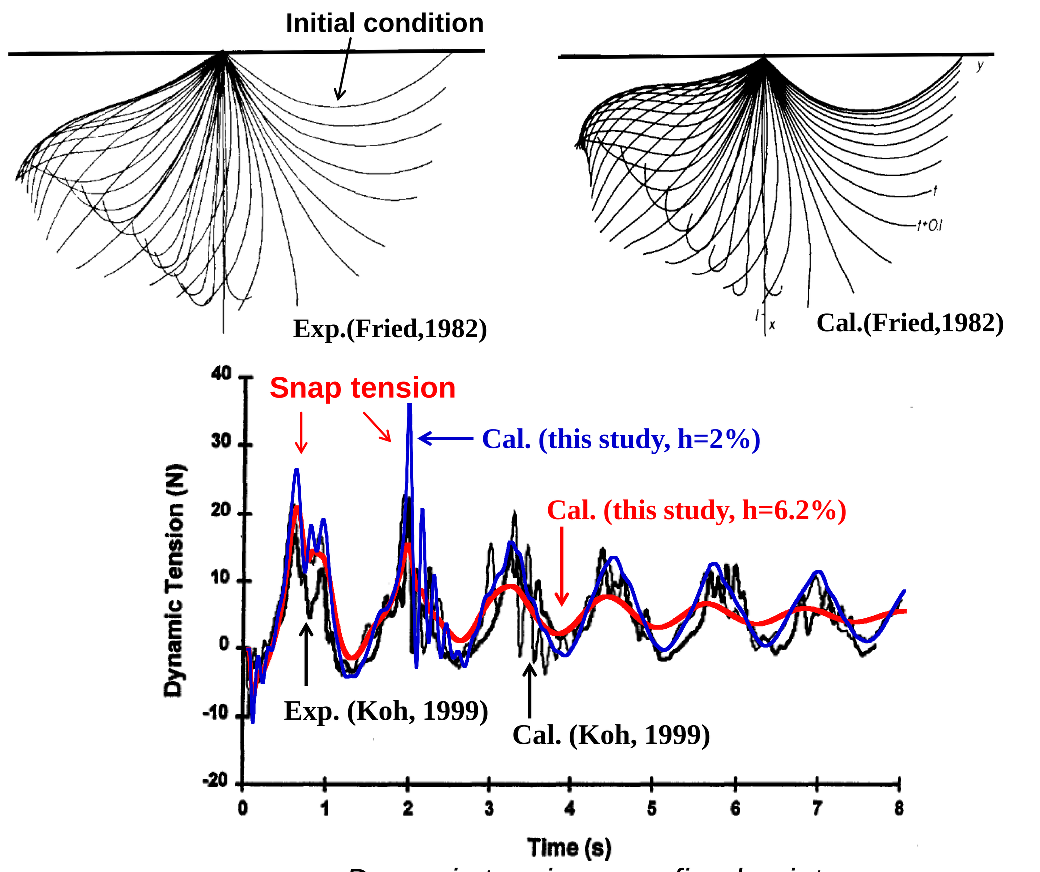
No of element	5
L (m)	18.9
m_c (kg/m)	0.0112
EA (kN)	134.2
Exciting freq. (Hz)	0.807, 1.27

(a) Non-resonant state

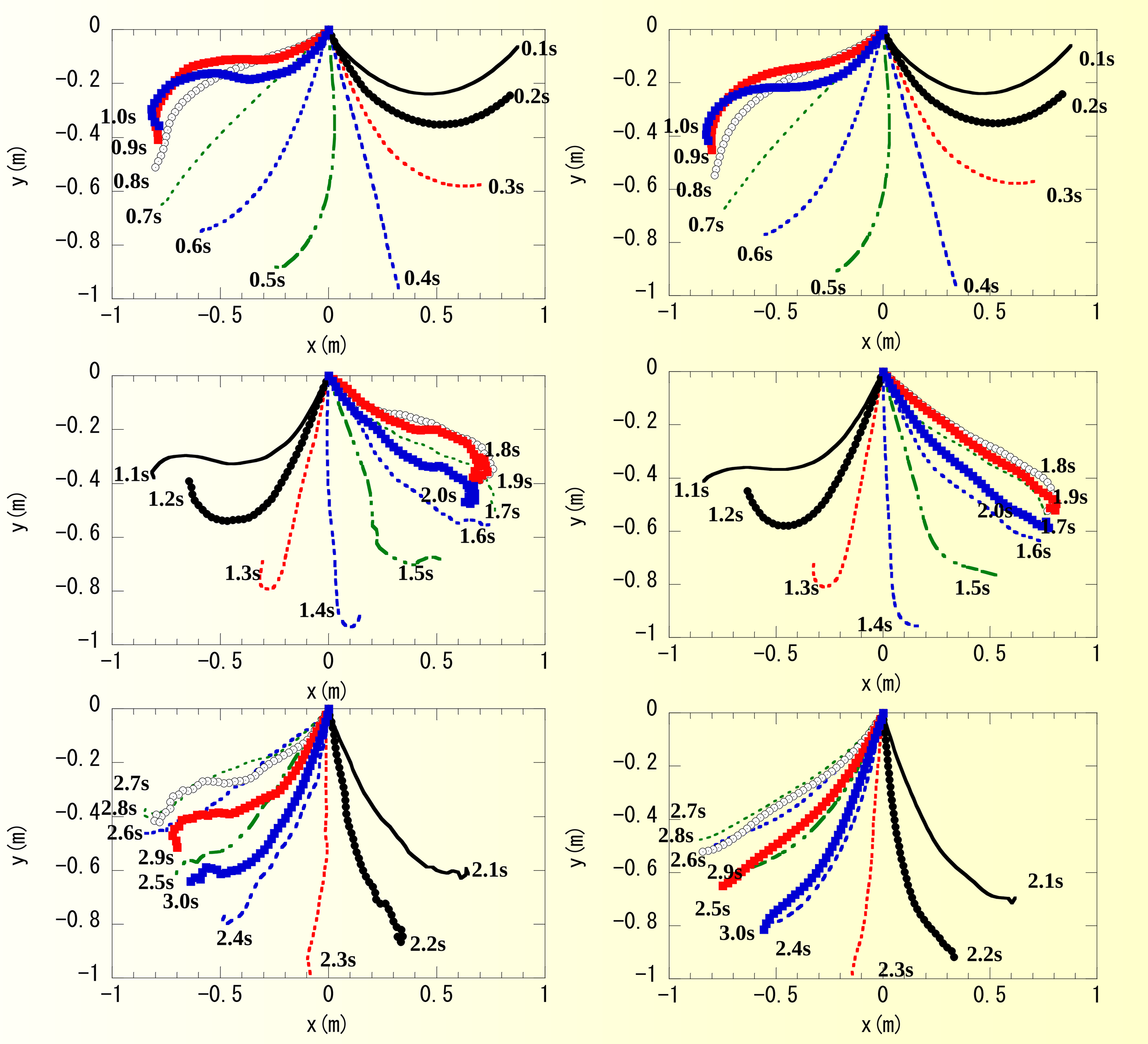
(b) Resonant state

■ Free swinging cable

- Simulated shapes of swinging cable are in good agreement with previous experimental and calculated results (Fried, 1982).
- Near the free end of cable, tension drops and the cable coils up into shape of high curvature that depended on the cable structural damping ratio
- Large snap tension occurred near the fixed point



Dynamic tension near fixed point



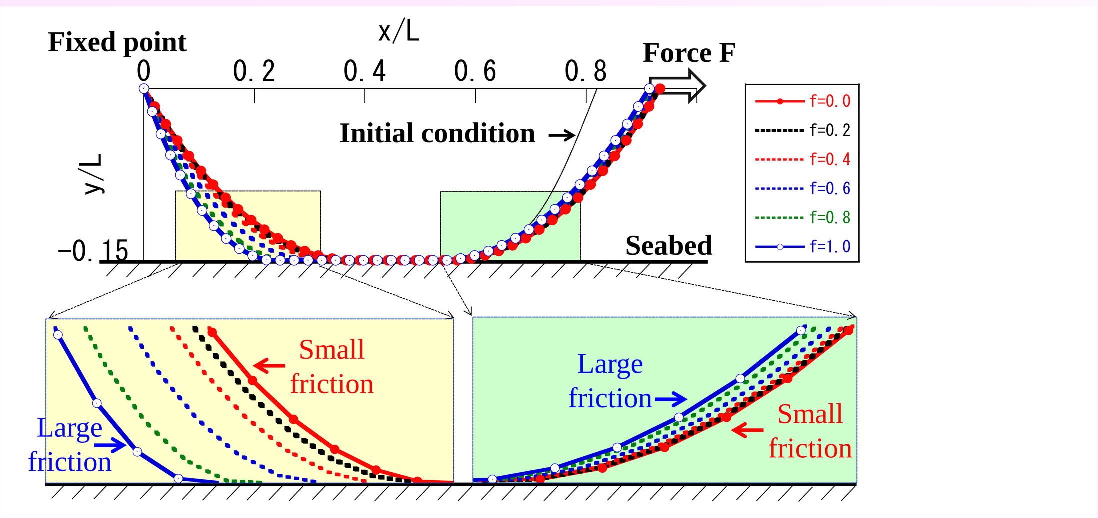
(a) Damping ratio h=1% *(b) Damping ration h=10%*

Shapes of free fall cable with different structural damping ratio (this study)

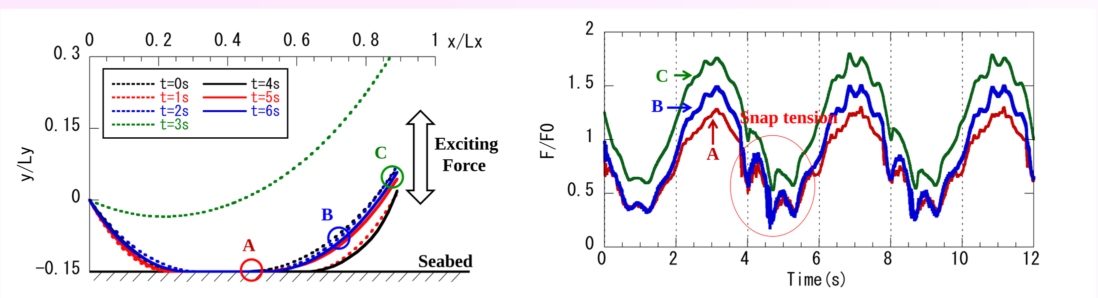
Mooring chain interaction with the Seabed

■ Preliminary test

- **Horizontal dragging :** profiles of the cable becomes asymmetrical when the friction forces from the seabed is large.
- **Vertical snapping :** Large snap tensions are found near the seabed by the dynamic response of cable in contact with the seabed



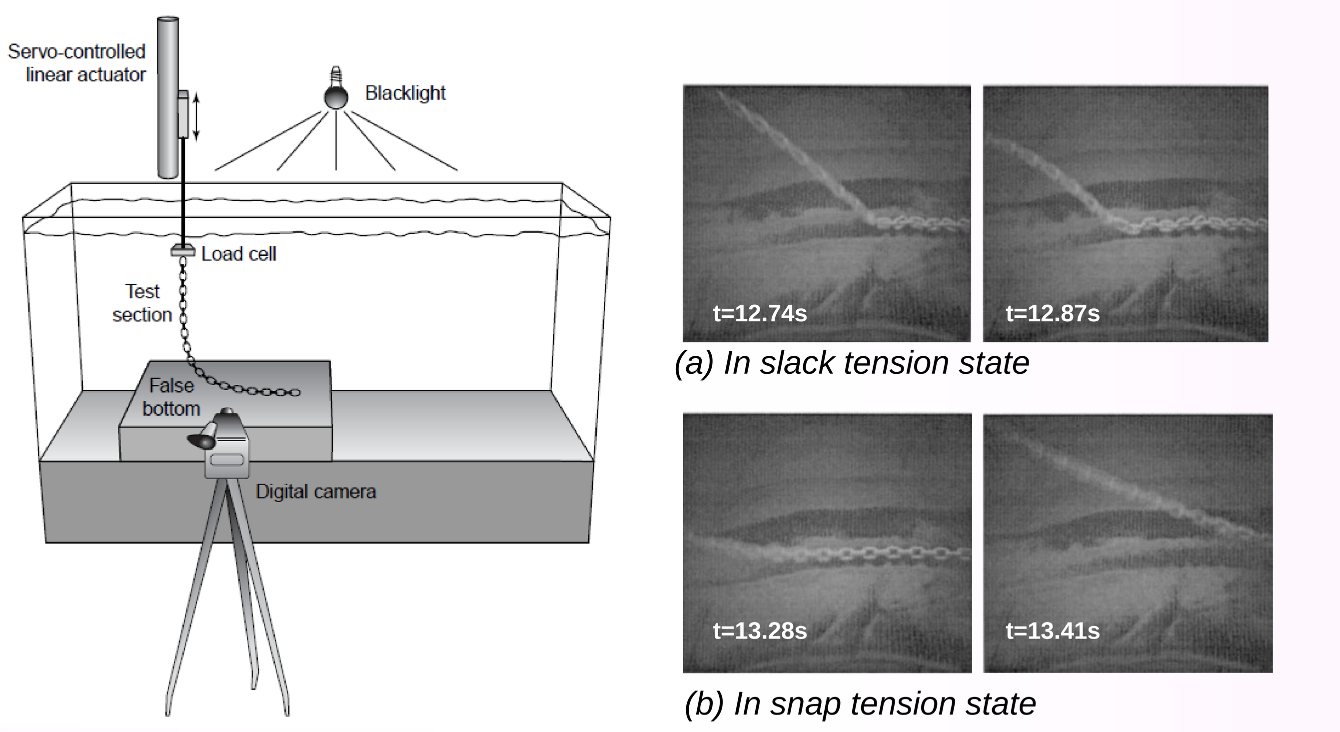
Profiles of horizontally dragged cable with different seabed friction factors



Dynamic response and tension of vertically snapped cable (T=4s, f=1.0)

■ Seabed interaction

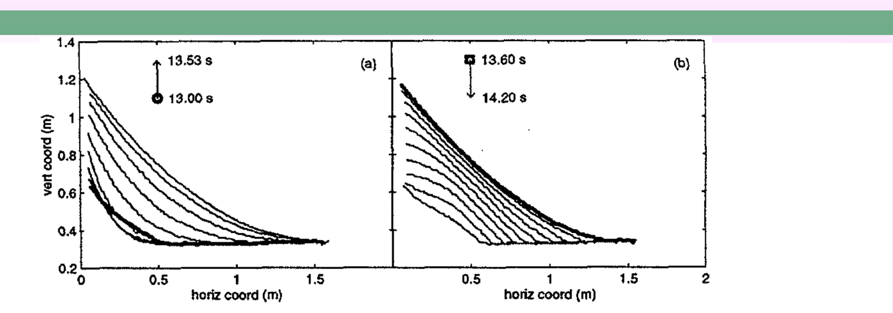
- Slack and large snap mooring tension was observed in previous experimental studies (Gobat, 2001)
- Simulated dynamic profiles of mooring chain is quite in good agreement with experimental results by Gobat(2001) for upward and downward motion the chain mooring cable.
- The simulated tension of mooring chain is well agreed with the experimental results both of in the slack and snap tension state.



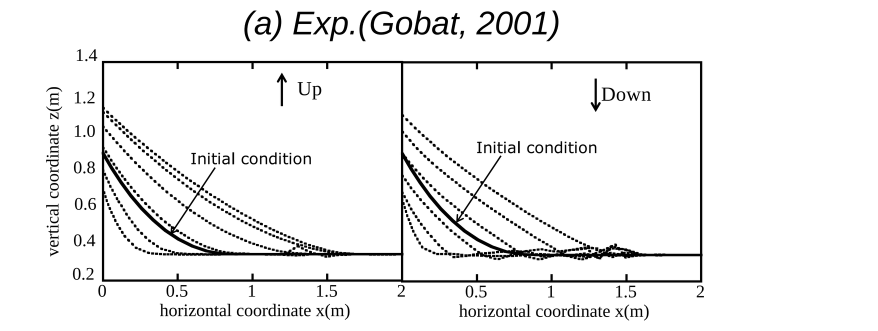
(a) In slack tension state

(b) In snap tension state

Experimental dynamics in the touchdown region of catenary mooring (Gobat, 2001)

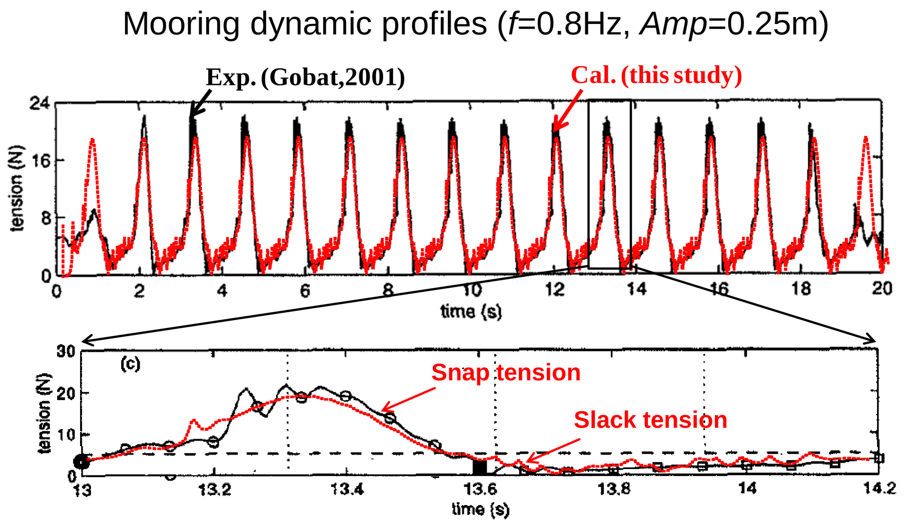


(a) Exp.(Gobat, 2001)



(b) Cal.(This study)

Mooring dynamic profiles (f=0.8Hz, Amp=0.25m)



Mooring tension time series (f=0.8Hz, Amp=0.25m)