The coupled vibration analysis for vertical pumps and the pump station

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Abstract

At the engineering stage of pump stations, the evaluation of the pump vibration is an important consideration.
Finite Element Method (FEM) is an effective method for prediction of vibration and avoidance of resonance phenomena.

At large-sized vertical pumps, stiffness of the foundation structure has a considerable effect on the natural frequencies.
Usually, pumps are installed on a high rigidity foundation.
In such a case, enough accuracy is obtained by a pump unit model supported by spring elements equivalent to the foundation stiffness.

However, if pumps are installed on a low rigidity foundation, there is a possibility that the following problems occur.

- Vibration interaction between pumps
- Vibration increase by the resonance of pump excitation frequencies and foundation natural frequencies.

Abstract

For these cases, the coupled vibration analysis of the pumps and the pump foundation structure is effective in obtaining low vibration levels.

The coupled vibration analysis enables an evaluation including interaction vibration of several structures by using the coupled model of these structures.

This presentation shows the case study of
the coupled vibration analysis
for three pumps and a pump station.

For the case study, the vibration levels of pumps were well below the vibration limits, because the prior review for the structure of the pump station was performed effectively by the analysis before the construction of the pump station.

Outline

seawater intake pump station for cooling water

Structure of the pump station

- The pump station is the steel framed reinforced concrete structure.
- For the structural reasons of the pit, the one side of the pump station is supported by the ground and the other side is supported by steel pipe piles.

It is necessary to confirm the rigidity to the dynamic load.

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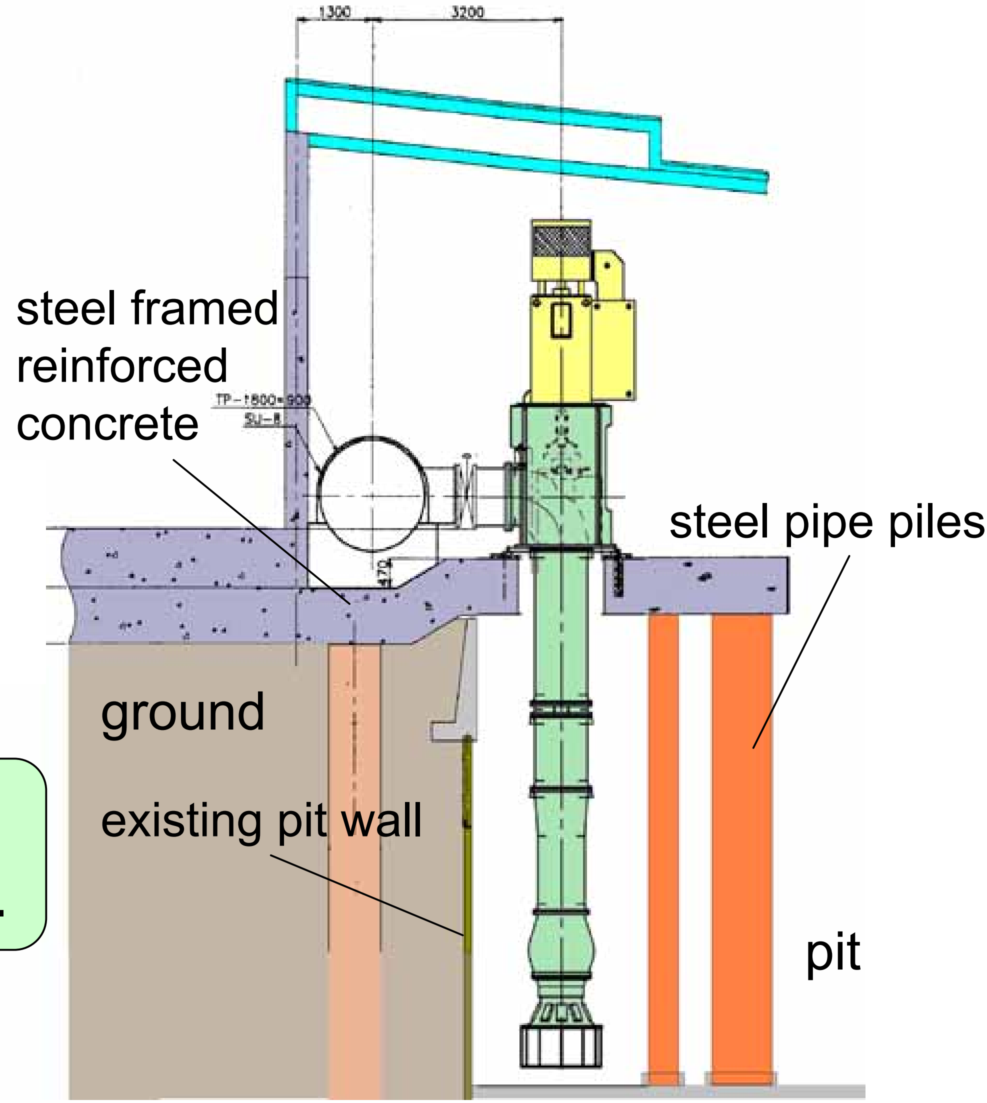
Prediction by FEM analysis



vertical cross-sectional view of the pump station

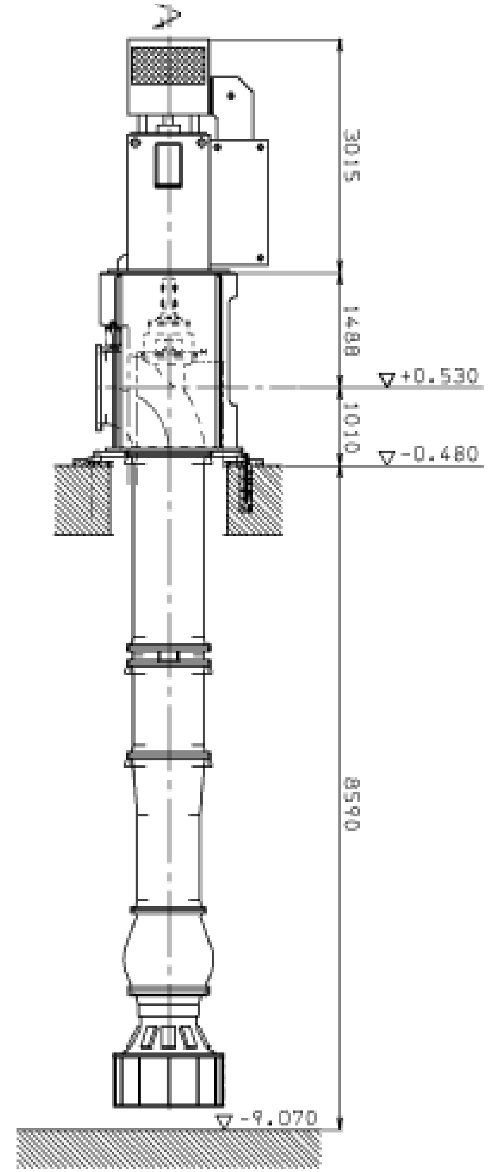
Outline

seawater intake pump station for cooling water

- 3 pump units are set on the pump station

Pump Specification

Pump type	Mixed flow Vertical Pump
Discharge Size	φ 900 mm (35.4 inch)
Capacity	130 m^3/min (34342.3 gpm)
Total Head	17 m (55.8 ft)
Speed	593 min^{-1}
Output of Motor	500 kW



Flow of the Case Study

STEP 1 Prediction of vibration amplitudes by the FEM analysis

For the prior review, vibration amplitudes of the pumps were calculated by the FEM vibration analysis using the coupled model of pumps and the pump station.

The pump station structure was decided based on the analysis.

STEP 2 Verification of the FEM model

The transfer function of the pump floor was measured by the excitation test.

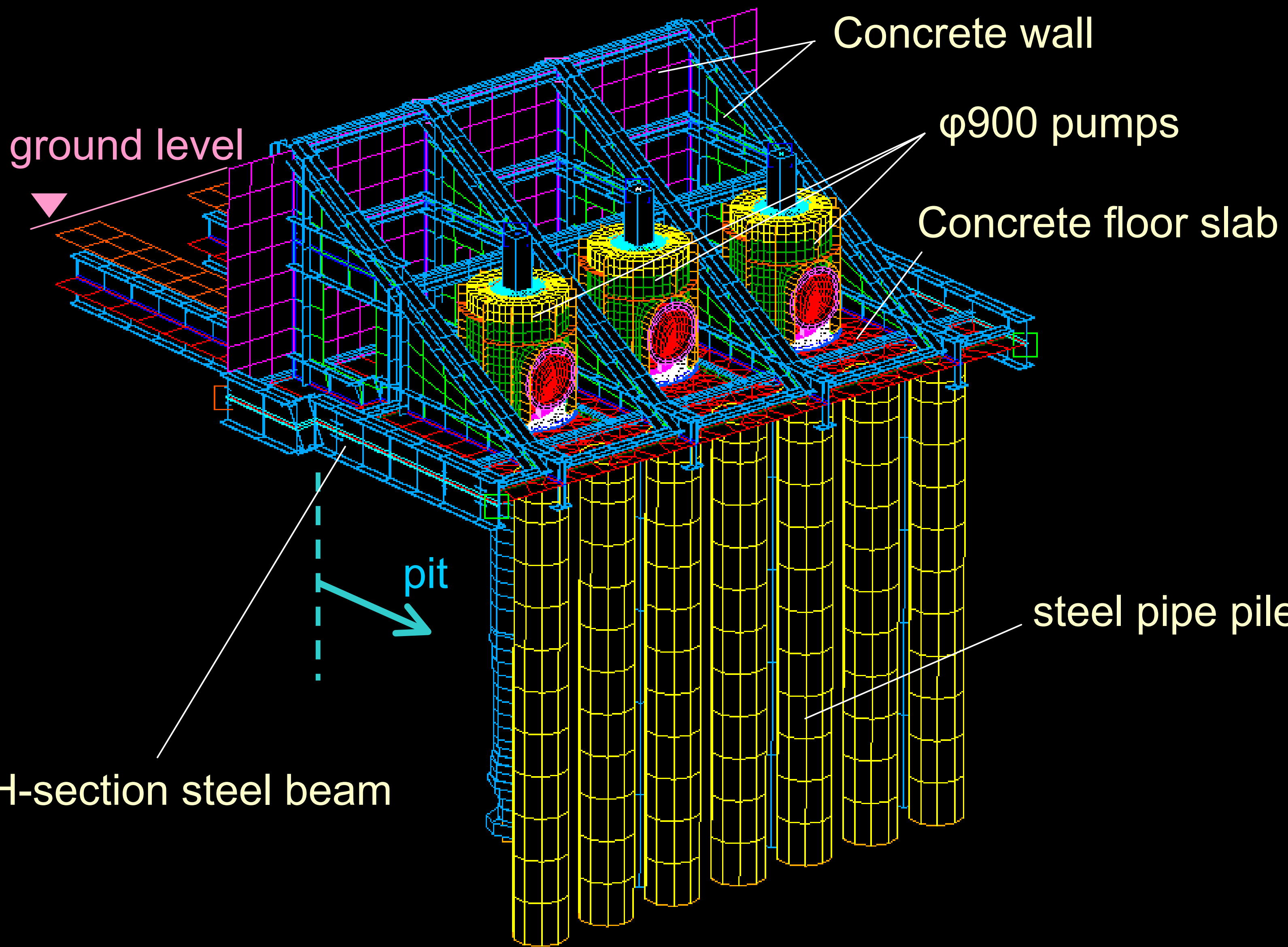
The FEM model was verified by the analytical transfer function with the measured transfer function.

STEP 3 Measurement of vibration amplitude at the operation

The accuracy of the analysis was verified by comparing results of the analysis with measurements at the pump operation.

Measurements were well below the vibration limit.

STEP 1-1 Model for FEM Analysis



Vibration amplitudes were calculated by the model.

STEP 1-2 Dynamic load condition for the prediction of vibration amplitude

		exciting force	exciting frequency
Motor	unbalanced force	343 N (77.1 lbf)	9.9Hz(N)
Pump Impeller	radial force (hydraulic at shut-off operation & structural unbalance)	6 860 N (1542.2 lbf)	9.9Hz(N) or 39.5Hz(ZN)
Pump thrust bearing	thrust force (10% of static pressure at shut-off operation)	9 800 N (2203.1 lbf)	9.9Hz(N) or 39.5Hz(ZN)

N: rotating frequency

ZN: blade passing frequency

Vibration amplitudes of the motors and the foundation were calculated by **the frequency response analysis** with these load conditions.

STEP 1-3 Results of frequency response analysis

Vibration limit : 80 μmP-P
(3.15 milsP-P)

Unit : μmP-P / milsP-P

		maximum values of the results of frequency response analyses
Motor	X	45.4 / 1.787
	Y	26.6 / 1.047
	Z	17.3 / 0.683
foundation	X	1.5 / 0.059
	Y	1.4 / 0.057
	Z	9.9 / 0.390

Analytical vibration amplitudes of motors were predicted below vibration limit.

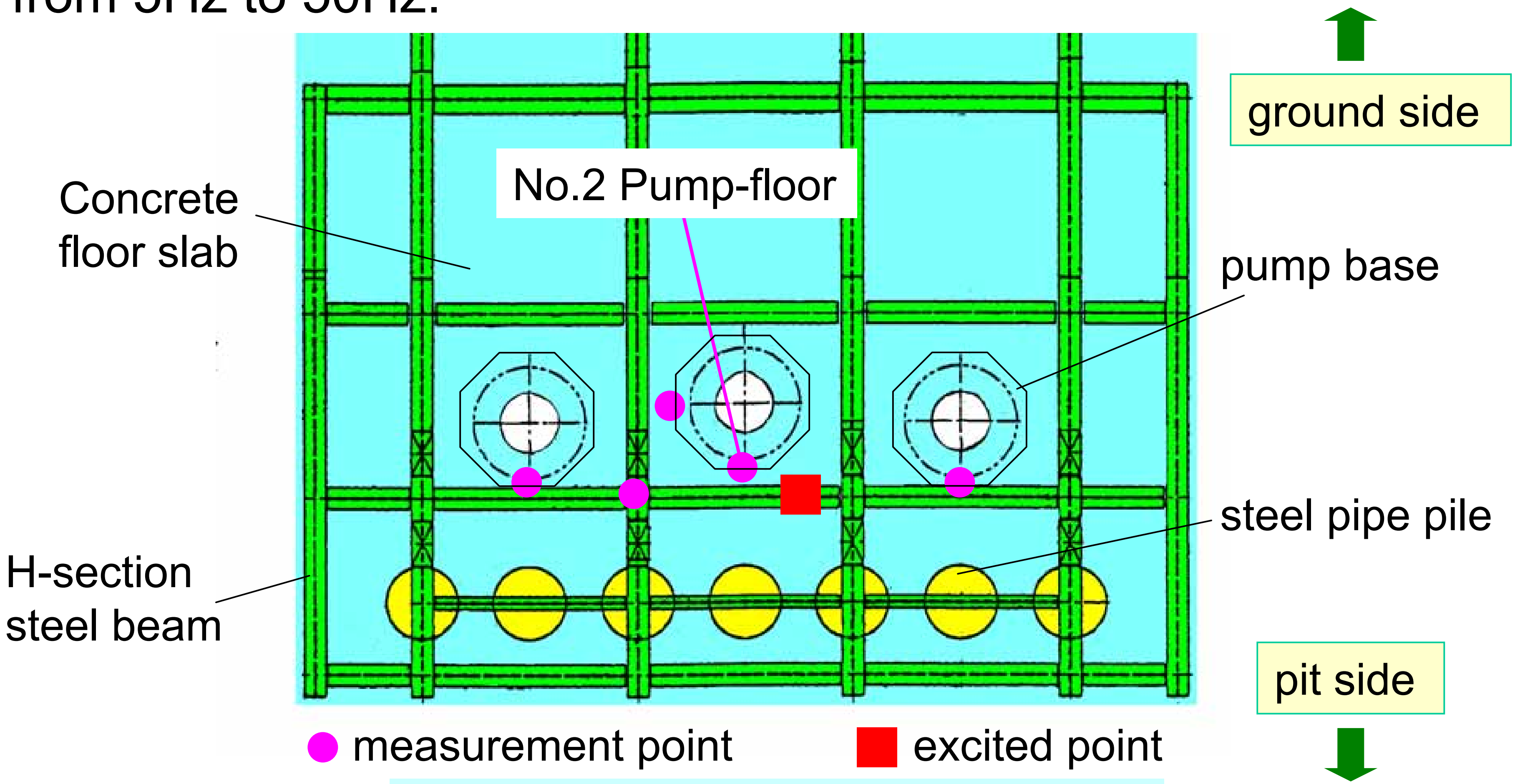
The foundation structure of the pump station was accepted.

X : pump discharge direction
Y : right angled direction of X in horizontal plane
Z : vertical direction

To improve the integrity, decrease of motor unbalance was requested to the motor vender.

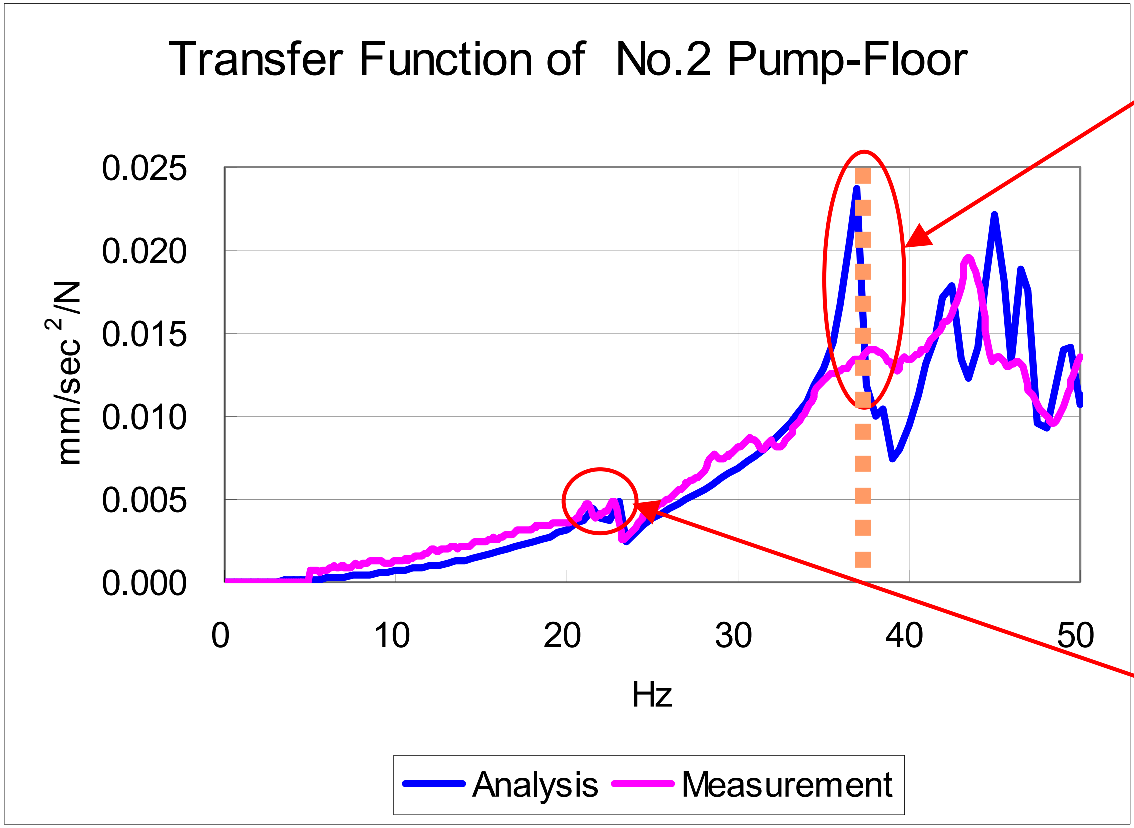
STEP 2-1 Measurement of transfer function for verification of the FEM model

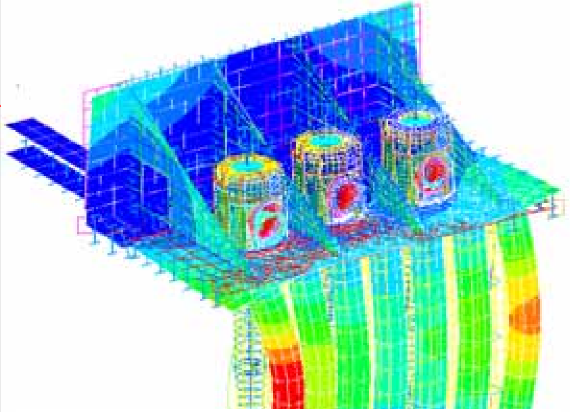
After the construction of the pump station,
the pump floor was excited by a vibration exciter at frequencies from 5Hz to 50Hz.



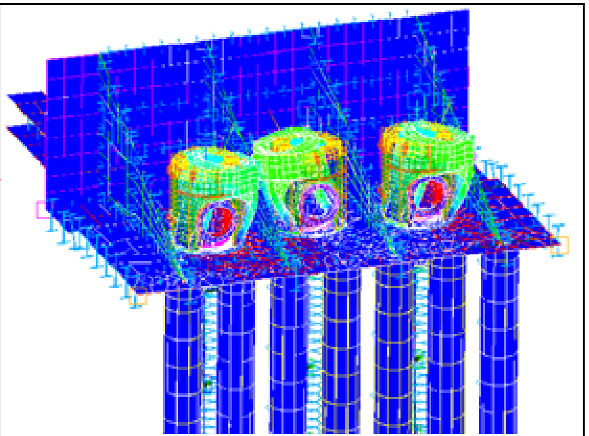
Excited point & measurement points

STEP 2-2 Comparison of transfer function between analysis and measurement





Natural frequencies of the entire pump station



Natural frequencies of Motor & Motor support

Analysis agrees with measurement.

The FEM model was verified.

STEP 3-1 Vibration amplitude by the analysis

Vibration limit : 80 μmP-P
(3.15 milsP-P)

Unit : μmP-P / milsP-P

		results of frequency response analyses
Motor	X	45.4 / 1.787
	Y	26.6 / 1.047
	Z	17.3 / 0.683
foundation	X	1.5 / 0.059
	Y	1.4 / 0.057
	Z	9.9 / 0.390

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Dynamic load condition	
Motor	unbalanced force
Pump Impeller	radial force (hydraulic at shut-off operation & structural unbalance)
Pump thrust bearing	thrust force (10% of static pressure at shut-off operation)

STEP 3-2 Comparison of vibration amplitude between analysis and measurement

Motor vibration amplitudes are less than results of analysis because the actual motor unbalance was lower than the analytical condition.

Vibration limit : 80 μmP-P (3.15 milsP-P)

Unit : μmP-P / milsP-P

		results of frequency response analyses	measurement		
			0%Q (shut-off)	33%Q	100%Q
Motor	X	45.4 / 1.787	12.1 / 0.476	16.1 / 0.635	3.6 / 0.140
	Y	26.6 / 1.047	12.5 / 0.491	9.6 / 0.380	5.4 / 0.213
	Z	17.3 / 0.683	5.9 / 0.233	5.8 / 0.229	3.3 / 0.128
foundation	X	1.5 / 0.059	3.2 / 0.124	2.0 / 0.080	0.4 / 0.017
	Y	1.4 / 0.057	2.0 / 0.078	1.6 / 0.061	0.6 / 0.024
	Z	9.9 / 0.390	2.8 / 0.110	4.8 / 0.190	0.6 / 0.024

Results of analyses agree with the measurement amplitude.

Conclusion

The vibration analysis by FEM can examine not only machine structure units but also large-scale issues between machines and foundation structures.

A case study of coupled vibration analysis for vertical pumps and a pump station was presented, and accuracy of the analysis was verified.

For high accuracy of coupled analyses for machines and foundation structures, the following knowledge is important,

- Modeling techniques for units of machine structures and foundation structures
- Definitions of boundary conditions and material properties such as stiffness and material damping.

Thank you for your kind attention.