A Study on the Comparison of wind pressure on the member of Container Crane using Wind tunnel test and CFD

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Abstract

Because strong wind is one of the few forces that, although considered in container crane design, still cause significant damage, a container crane was tested to investigate wind load characteristic in uniform flows. So, this study measured an external point pressure at the each members of a container crane according to a wind direction and a shape of members in a wind-tunnel test. The result of this test was compared to those of computation fluid dynamics using a CFX 10. The scale of a container crane model for wind tunnel test applied similarity scales to consider the size of the wind tunnel test section and the boundary condition for CFD is like wind tunnel test.

Keywords: Wind tunnel, Wind pressure, Container crane, Computation Fluid Dynamic

1. Introduction

A container crane operates under weakness condition because there is no shielding facility to protect the container crane from storm wind. Those container crane mainly used in the current berth can reach maximum 100m at stowed mode (a certain condition that boom has been raised)[1]. Therefore, it may easily affect by wind load. Especially, in the event of sudden attack by the typhoon “Maemi” totally 11 number of the container crane was broken in the reason of heavy wind load. So, it is caused extravagant loss in the field of physical distribution.

So, wind load is considered the most important factor in any load conditions of the container crane design. For example, it is not only applied to analyze a structural strength of each member of the container crane but also design a stowed device (tie-down, stowage pin and rail clamp, etc.) to prevent the container crane from overturning[2].

To calculate a wind load applied on the container crane accurately, wind tunnel test for a container must be done.

In this study, we measured an external point pressure at the each member of the container crane according to a wind direction and a shape of members using the wind-tunnel test. The result of this test was compared to those of Computation Fluid Dynamics using a CFX 10.

We used the miniature of 50ton container crane which can widely use in the berth for the wind tunnel test.

2. Wind Tunnel Test

2.1 Experimental Facilities and Measuring Equipments

2.1.1 Subsonic Wind Tunnel

To measuring the wind load of the container crane, a Subsonic Wind Tunnel which is suction type by the impeller was used. Total length is 2.98m, width is 0.8m and height is 0.83m. The range of effective wind velocity is 9m/s (30V) ~15m/s(50V). Fig. 1 shows the wind tunnel used in this experiment.

Figure 1. Subsonic Wind Tunnel

2.1.2 Wind Velocity and Model Design

This paper assumed that a wind load at 75m/s velocity is applied on a container crane. By similarity[3], the experimental wind velocity is 15m/s. Each member of the container crane which used in this wind test was designed by Eq. (1). Here V is wind velocity, L and T is geometrical dimension and measuring time.

$$V_{model} = V_{full} \ \text{x} \ (L_{model} / L_{full}) \ \text{x} \ (T_{full} / T_{model}) \quad (1)$$

A wind pressure which applied on the member is measured by semiconductor pressure sensor which connected pressure hole at the member’s surface by a tube. And the wind velocity is also applied to the container crane members with two directions. Each member of the container crane for the wind tunnel test is designed considering of that. Twenty-four container crane members were designed for this wind tunnel test. The material of member is acrylic.

Container crane member’s drawing is shown in Fig. 2.

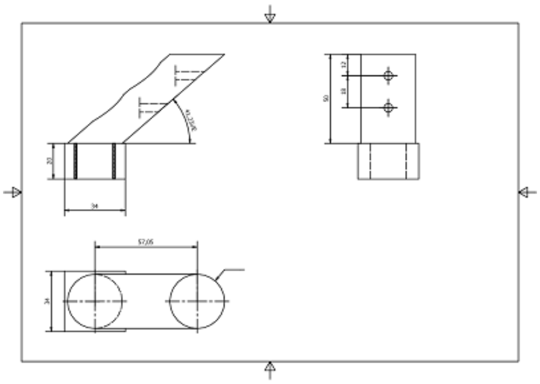

Figure 2. Drawing of Low Diagonal

2.1.3 Semiconductor Pressure Sensor for Wind Tunnel Test

For the measurement of wind pressure at the members of the container crane, a semiconductor sensor as shown in Fig.3 was used. The two holes are connected by a tube to the pressure hole at the member's surface and wall of the wind tunnel.
Table 1 presents specifications of semiconductor pressure sensor.

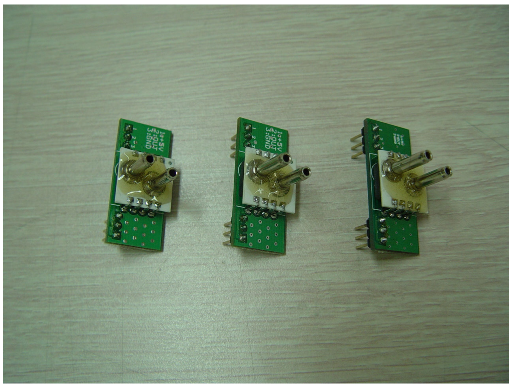

Figure 3. Semiconductor Pressure Sensor

Table 1. Specifications of semiconductor pressure sensor

Function	Semiconductor Pressure Sensor		
Available Pressure	max. 500Pa		
Output Form	Voltage Output		
Performance	Nom.	Min.	Max.
Input Voltage	DC 5V	DC 4.5V	DC 5.3V
Input Current	1.5mA	1.5mA	1.5mA

2.1.4 Wind Pressure Monitoring System

To measurement wind pressure, a seaparate monitoring system is necessary in the wind tunnel test. In this study, the monitoring system which taken a signal from the semiconductor pressure sensor was designed. It consisted of Power, Bread Board, Microprocessor, A/d converter and LCD. The voltage of the semiconductor pressure sensor is sent to Microproces sor and then to the A/D converter. Lastly the signal is disp layed at the LCD. Six semiconductor pressure sensor can co nnect to bread board at a maximum capacity.

Wind pressure monitoring system is shown in Fig. 4.

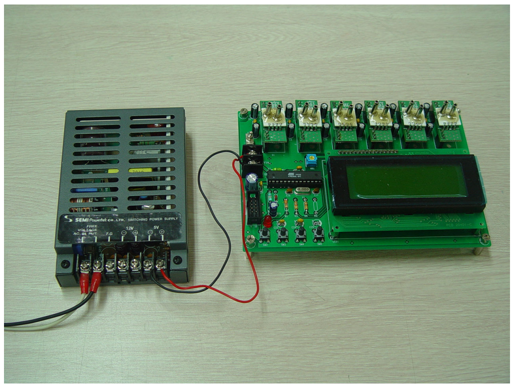

Figure 4. Wind Pressure Monitoring System

2.2 Experimental Process

The experimental process is as follows

First, the semiconductor pressure sensor connected by a tube to the pressure hole at the member's surface. Then a reducing member of the container crane was installed in the subsonic wind tunnel and then 15m/s wind velocity was simulated in the wind tunnel.

Static pressure in the wind tunnel was measured by semi-conductor pressure sensor through the pressure tube which connected in the wind tunnel. The semiconductor pressure sensor was calculating a difference pressure between static pressure in the wind tunnel and dynamic pressure at the member's surface. Then the difference pressure was displayed at the LCD.

In this same way, the wind tunnel test was carry out for twenty-four members of container crane.

Experimental setup is given in Fig. 5 and Fig. 6 being shown the wind pressure measured by semiconductor pressure sensor.

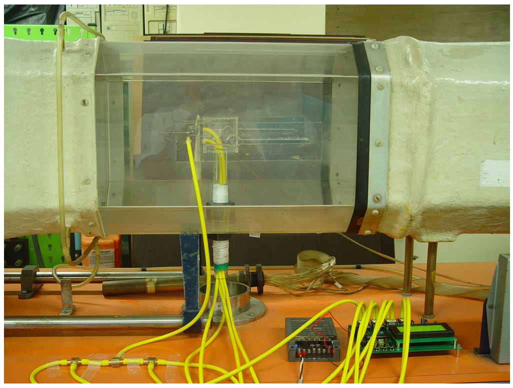

Figure 5. Experimental Setup

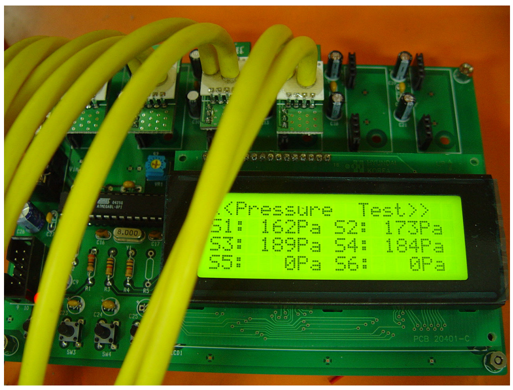

Figure 6. Wind pressure displayed at the monitoring system.

2.3 Result of Wind Tunnel Test

2.3.1 Mean Wind Pressure

In this study, the wind pressure was measured at the center of member. Because, the wind pressure is significantly differ in the surface location and the shape of member.

Table 2 presents mean wind pressure at the center of container crane members. Mean pressure was calculated on the ten repeating values except maximum and minimum.

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Table 2. Mean Wind Pressure at the center of members

Member	Mean Pressure	Member	Mean Pressure
Apex Beam	243	Lower Leg-X	266
Portal Beam	299	Lower Leg-Z	290
TG End Tie	183	Mc House-X	291
Boom Cross	251	Mc House-Z	399
TGSB	250	Apex Beam-X	362
Upper Dia-X	146	Apex Beam-Z	392
Upper Dia-Z	203	Sill Beam	387
Lower Dia-X	141	Trolley Girder	394
Lower Dia-Z	185	Boom-X	356
Upper Leg-X	402	Boom-Z1	291
Upper Leg-Z	352	Boom-Z2	340

2.3.2 Wind Pressure Coefficient

The wind pressure coefficient which means the relationship between the static pressure and the dynamic pressure can be calculated by Eq. (2).

$$C_p = \frac{\overline{P}}{q_H} \tag{2}$$

Where, C_p is wind pressure coefficient, $\overline{P}$ is the mean wind pressure at the surface of members, and q_H is the static pressure in the wind tunnel. Wind velocity in the wind tunnel is 15m/s and then the static pressure is 137.95 Pa.

Wind pressure coefficient of container crane members are given in Table 3.

Table 3. Wind pressure coefficient of container crane members

Member	Coefficient	Member	Coefficient
Apex Beam	1.76	Lower Leg-X	1.93
Portal Beam	1.76	Lower Leg-Z	2.10
TG End Tie	1.33	Mc House-X	2.11
Boom Cross	1.82	Mc House-Z	2.89
TGSB	1.81	Apex Beam-X	2.62
Upper Dia-X	1.06	Apex Beam-Z	2.84
Upper Dia-Z	1.47	Sill Beam	2.81
Lower Dia-X	1.02	Trolley Girder	2.86
Lower Dia-Z	1.34	Boom-X	2.58
Upper Leg-X	2.91	Boom-Z1	2.11
Upper Leg-Z	2.55	Boom-Z2	2.46

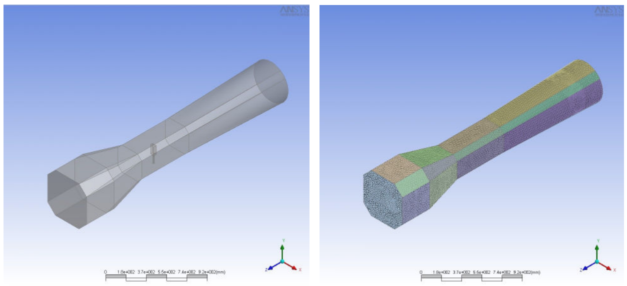
3. Computation Fluid Dynamic

3.1 CFD (computation fluid dynamic) Profile

In this study, Autodesk Inventor 9.0 was used to create 3D-model of the container crane members. And to generation Fluid Mesh, ANSYS CFX Mesh was used. Computation Fluid Dynamic was performed using ANSYS CFX 10.

3.2 Model for CFD

To create the same experimental circumstance, the shape and dimension of container crane members are equal to the experimental of it. The model and Fluid Mesh for Computation Fluid Dynamic is given in Fig. 7.



(a) 3-D Model (b) Fluid Mesh

Figure 7. 3-D Model and Fluid Mesh for Computation Fluid Dynamic.

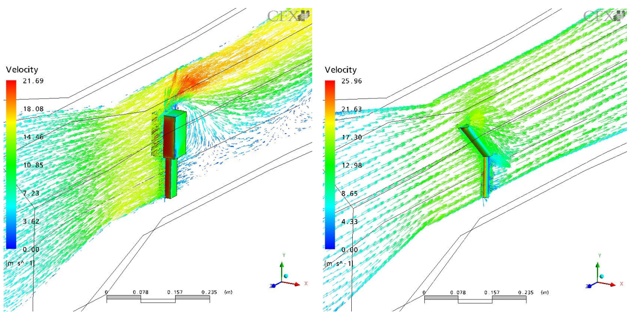
3.3Boundary Condition for CFD

The conditions of Computation Fluid Dynamic for the container crane member were created equal to the experimental of it. The inside of subsonic wind tunnel made of Fluid Field. And then 15m/s of wind velocity applied to an entrance of wins tunnel. Outlet is the static pressure, wall of wind tunnel is No-Slip and Smooth Wall boundary condition. Air density is 0.125 kgf·s^2/m^4.

3.4Result of CFD

3.4. Mean Wind Pressure

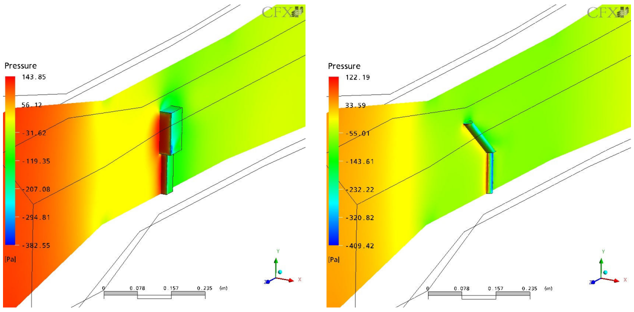
Wind velocity distribution around the container crane members in the CFD when a wind velocity applied on the member to x direction is given in Fig. 8.



(a) Lower Leg (b) Low Diagonal

Figure 8. Wind velocity distribution around the container crane members.

And wind pressure distribution around the container crane members in the CFD when a wind velocity applied on the member to x direction is given in Fig. 9.



(a) Lower Leg (b) Lower Diagonal

Figure 9. Wind pressure distribution around the container crane members.

In CFD, the wind pressure which applied on the container crane members was measured at the same displacement as that of experimental members. Table 4 presents mean wind pressure at the center of the container crane members.

Table 4. Mean Wind Pressure at the center of the container crane members.

Member	Mean Pressure	Member	Mean Pressure
Apex Beam	91	Lower Leg-X	131
Portal Beam	112	Lower Leg-Z	67
TG End Tie	149	Mc House-X	89
Boom Cross	57.25	Mc House-Z	75
TGSB	110	Apex Beam-X	78
Upper Dia-X	-12	Apex Beam-Z	72
Upper Dia-Z	75	Sill Beam	146
Lower Dia-X	-5	Trolley Girder	76
Lower Dia-Z	75	Boom-X	62
Upper Leg-X	78	Boom-Z1	71
Upper Leg-Z	74	Boom-Z2	60

3.4.2 Wind Pressure Coefficient

The wind pressure coefficient of the container crane was calculated by Eq. (2). Wind velocity in the wind tunnel is 15m/s and then the static pressure is 137.95 Pa. Wind pressure coefficient of the container crane members are given in Table 5.

Table 5. Wind pressure coefficient of container crane members

Member	Coefficient	Member	Coefficient
Apex Beam	0.66	Lower Leg-X	0.95
Portal Beam	0.81	Lower Leg-Z	0.49
TG End Tie	1.08	Mc House-X	0.65
Boom Cross	0.41	Mc House-Z	0.54
TGSB	0.8	Apex Beam-X	0.57
Upper Dia-X	-	Apex Beam-Z	0.52
Upper Dia-Z	0.54	Sill Beam	1.06
Lower Dia-X	-	Trolley Girder	0.55
Lower Dia-Z	0.54	Boom-X	0.45
Upper Leg-X	0.57	Boom-Z1	0.51
Upper Leg-Z	0.54	Boom-Z2	0.43

4. Results and Discussions.

In this study, a wind load which applied on the container crane members was derived from the wind pressure coefficient that was calculated in Section 2 and Section 3. The wind load was calculated by Eq. (3).

$$P = C_p \times \overline{p} \times A \tag{3}$$

Here C_p is wind pressure coefficient, $\overline{P}$ is the mean wind pressure at the surface of members, and A is effective area.

The wind load according to the wind direction was compared to the 'Design Criteria of a Road Bridge' of Ministry of Construction and Transportation in Korea.

Wind load which applied on the container crane member according to the wind directions are given in Table 6 and Table 7.

Table 6. X-direction wind load at the container crane members

Member	DCRB	Wind Test	CFD
Lower Leg	302	488	240
Upper Leg	903	1,278	250
Apex Leg	242	437	95
Apex Beam	59	69	26
Portal Beams	0	0	0
Lower Diagonal	89	159	-
Upper Diagonal	95	197	-
Sill Beam	205	349	132
TGSB	307	337	149
Trolley Girder	0	0	0
Boom	525	648	226
TG End Tie	91	109	88
Boon End Tie	33	28	6
Boom Cross 1	47	50	11
Boom Cross 2	51	28	12
Mc. House	308	562	173
Total	3,257	4,739	1,408

Table 7. Z-direction wind load at the container crane members

Member	DCRB	Wind Test	CFD
Lower Leg	205	943	110
Upper Leg	490	746	158
Apex Leg	352	592	108
Apex Beam	0	0	0
Portal Beams	455	474	218
Lower Diagonal	133	209	84
Upper Diagonal	148	276	101
Sill Beam	0	0	0
TGSB	0	0	0
Trolley Girder	988	1,341	258
Boom	705	1,222	256
TG End Tie	0	0	0
Boon End Tie	0	0	0
Boom Cross 1	0	0	0
Boom Cross 2	0	0	0
Mc. House	193	482	90
Total	3,669	6,286	1,384

Most of the wind load which measured by the wind tunnel test are higher than the result of CFD and Design Criteria of a Road

Bridge. This was an error which occurred at the measuring process in wind tunnel test.

The wind load which measured by CFD is 30~80% less than Criteria of a Road Bridge.

5. Conclusion.

In this study, by measuring the wind pressure on the surface of the container crane members using semiconductor pressure sensor and wind pressure monitoring system, we furnished wind pressure coefficient and each directional wind load which can applied on the container crane members. And it was compared with the result of computation fluid dynamic and Design Criteria of a Road Bridge.

Because of the error which occurred at the measuring process in wind tunnel test, the wind pressure is greatly measured. As a result, we confirmed the wind load which applied on the container crane member is 45~75% higher than the Criteria of a Road Bridge and the result of computation fluid dynamic.

But we easily access to the wind pressure test using subsonic wind tunnel, semiconductor pressure sensor and the monitoring system. It carry an important meaning.

Hereafter, if we modify the error of wind tunnel test, the wind pressure will be getting more precisely.

Acknowledgement

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