A Study on the Estimation of the Structural Stability of a Container Crane According to the Change of the Boom Shape using Wind Tunnel Test

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ABSTRACT

In this study we carried out to analyze the effect of wind load on the structural stability of a container crane according to the change of the boom shape using wind tunnel test and provided a container crane designer with data which can be used in a wind resistance design of a container crane assuming that a wind load at 75m/s wind velocity is applied on a container crane.

Data acquisition conditions for this experiment were established in accordance with the similarity. The scale of a container crane dimension, wind velocity and time were chosen as 1/200, 1/13.3 and 1/15. And this experiment was implemented in an Eiffel type atmospheric boundary-layer wind tunnel with 11.52m^2 cross-section area. Each directional drag and overturning moment coefficients were investigated and uplift forces at each supporting point due to the wind load were analyzed.

1. Introduction

Container cranes are vulnerable to difficult weather conditions because there is no shielding facility to protect them from high winds. Container cranes in current use can reach a maximum height of 100m in stowed mode (i.e. when the boom has been raised). Therefore, they may easily be affected by wind load, especially in the case of the sudden onset of the typhoon "Maemi," where a total of 11 container cranes were damaged due to heavy wind load, causing heavy losses for the Korean logistics sector.

So, wind load is considered the most important factor under any load conditions for container crane design. For example, wind load is not only applied to analyze the structural strength of each part of a container crane, but also in the design of stowing devices (tie-down, stowage pin and rail clamp, etc.) to prevent container cranes from overturning (J. of KSPE, 2004).

To calculate the wind load applied to a container crane accurately, both a basic design test and a wind tunnel test must be done. These tests are divided into two stages by Korean container crane manufacturers. The basic design test is performed in house using the 'BS2573' standard. However, for the wind tunnel test, they use data provided by a foreign consultative committee.

Unfortunately this happens to reduce the reliability of a container crane, because the wind tunnel test model parameters established by the foreign consultative committee are different from those required for domestically produced container cranes.

As a container crane was installed on a height restrict region near an airport or many other factors, the boom with conventional 'I' shape, shown in Fig. 1, could not be used for a container crane because the total height exceeded the limitation. Therefore, in order to resolve this restriction, container crane designers devised an articulation type boom, shown in Fig. 2, or a travel type boom.

But most container crane manufacturers applied the wind tunnel test results from a container crane with a conventional 'I' shape boom to an articulation type container crane even though the articulation type container crane need to be analyzed for structural stability. So, the effect of wind load on an articulation type container crane was not investigated precisely in design.

Therefore, this study was carried out to analyze the effect of wind load on the structural stability of a container crane according to the change of the boom shape through a wind tunnel test and provide container crane designers with data to enable the design of wind-resistant container crane to be suitable for Korean conditions.

2. Wind Tunnel Test

2.1 Design of Wind Velocity and Wind Characteristics

In this study the wind tunnel test was carried out on the assumption that a wind load of 75m/s velocity is applied to a container crane. Mean wind velocity according to height conformed to 'Design Criteria of a Road Bridge' and

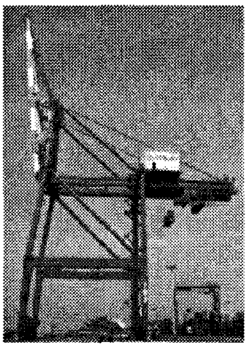


Fig. 1 A container crane with conventional type boom

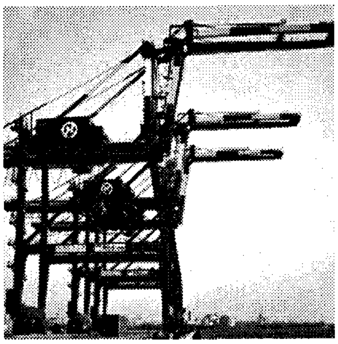


Fig. 2 A container crane with articulated type boom

turbulence intensity and wind velocity spectrum conformed to 'Load Criteria of Building Structures' (both Ministry of Construction & Transportation of the Korean Government, 2000). As a container crane is generally installed on a shoreline, the terrain roughness category was selected to be Exposure I (Design Criteria of a Road Bridge) and Exposure D (Load Criteria of Building Structures) in the boundary layer for the wind tunnel test.

Fig. 3 shows the vertical distribution of mean wind velocity and turbulence intensity, and the wind velocity spectrum at a height of 64m (32cm in wind tunnel test model), which is the apex beam location of the container crane shown in Fig. 4.

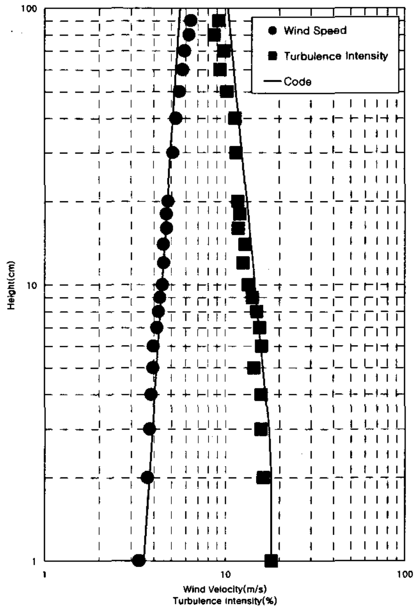


Fig. 3 Wind velocity and turbulence intensity according to height

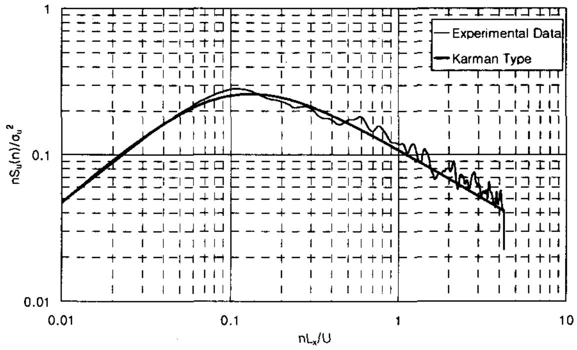


Fig. 4 Wind velocity spectrum at 32cm height in the wind tunnel

2.2 Experimental Facilities and Measuring Equipments

The wind tunnel used for measuring the wind load is an Eiffel type atmospheric boundary-layer wind tunnel at the Hyundai Institute of Construction Technology. The total length is 53m, and the dimensions of the measuring part are 4.5m (width)×2.5m (height)×25m (length). Its wind velocity range is 0.3 ~ 17.5m/s and turbulence intensity is under 0.7%. Fig. 5 shows the wind tunnel (J. of WEIK, 1997).

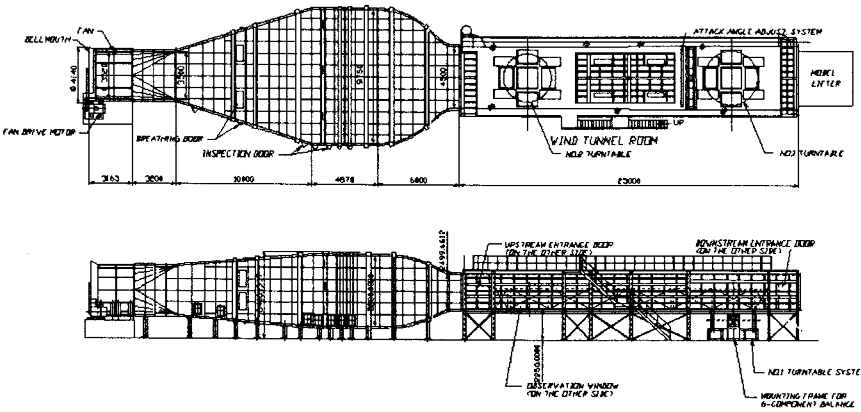


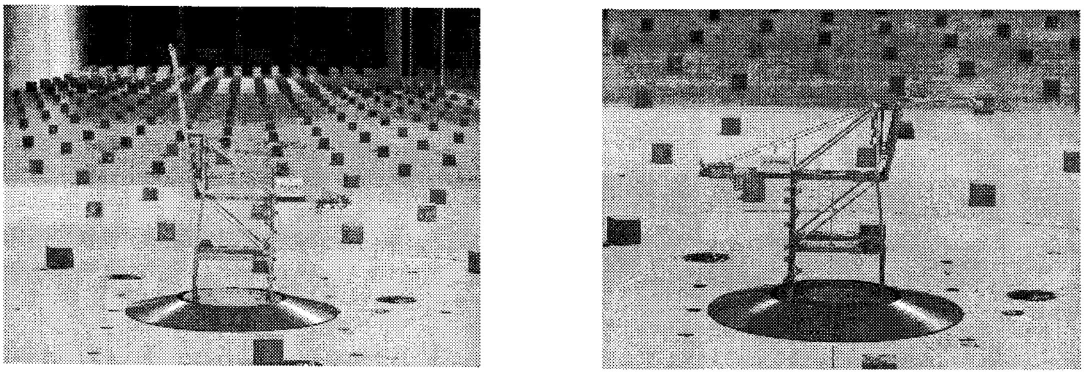
Fig. 5 Boundary layer wind tunnel

The measuring equipment used in this experiment are as follows :

- 6-component load cell : LMC-6524-10S (NEW)
- Hot wire anemometer : Model 1008 (KANOMAX)
- Digital micro manometer : DP-20A (Okano)
- Dynamic strain amplifier : DSA-100 (NEW)
- Low pass filter : 9B02 (NEC)
- Digital barometer : BN60705 (S.I.)
- ADC : AT-MIO-16XE-50 (N.I.)

2.3 Experimental Model

The wind tunnel test model used in this experiment is shown in Fig. 6.



(a) Conventional type boom model

(b) Articulated type boom model

Fig. 6 Container crane models installed in boundary layer wind tunnel

It is a 1/200 reduced scale model of a container crane type widely used in Korean berths. The original crane has a 50-ton lifting capacity, 890 tons weight and 51m outreach. The height of the girder from the ground is 40m and the height of the boom end tie in stowed mode can reach 100m (HHIC, 2000). The material used for the scale model is balsa wood, and to increase the natural frequency of the model it is constructed to be light and stiff.

In order to make an experiment on the estimation of the structural stability of a container crane according to the change of the boom shape, we makes two different models, conventional type boom model (model 1) and articulated type boom model (model 2). And to evaluate the stability of a container crane according to its machinery house location, whereby the machinery house makes up approximately 15% of the crane's total weight, we install a representative machinery house in three specific cases; D=6m (30mm in model / case 3), 13m (65mm in model / case 2), and 33m (165mm in model / case 1), where D represents the distance of the machinery house from the intersecting point of girder, boom, and leg.

2.4 Experimental Process

The experimental process is as follows.

First, the boundary layer in wind tunnel was simulated to represent the designed wind velocity of 75m/s (fastest velocity) and the shoreline terrain roughness category. The 1/200 reduced scale model of a container crane was installed on top of a 6-component load cell.

Then, each directional drag and overturning moment coefficient was measured with respect to the change of incidence angle of the wind load from Case 1, where the machinery house is located outside the land side leg. At this point, we measured these data at 10-degree intervals from 0-degrees to 180-degrees, because a container crane is a symmetrical model.

In the other cases, where the machinery house is moved to the sea side leg, we measured wind load coefficients by the same experimental process. Using these results, we calculated the wind load and overturning moment applied to a container crane, and the uplift forces at each supporting point.

Fig. 7 shows the flow chart for the wind tunnel test of the container crane model, and the definition of incidence angle of wind load is shown in Fig. 8.

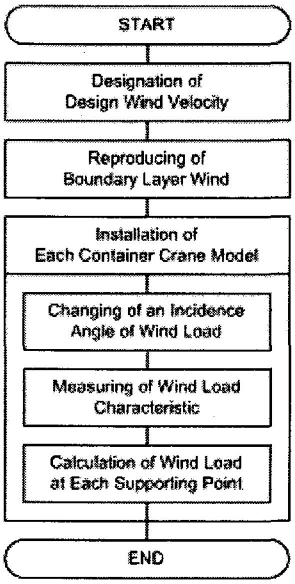


Fig. 7 Flow chart of the wind tunnel test of the container crane

Data acquisition conditions for this experiment are as follows :

- Model scale : 1/200
- Wind velocity scale : 1/13.3
  - Design wind velocity : 75m/s (at 64m height)
  - Wind tunnel test velocity : 5.6m/s (at 32cm height)
- Time scale : 1/15
  - Actual time : 600sec
  - Wind tunnel test time : 40sec
- Scaling frequency : 120Hz
- Number of measurements : 10times
- Total number of data : 120Hz 40sec 10times = 48,000EA / ch

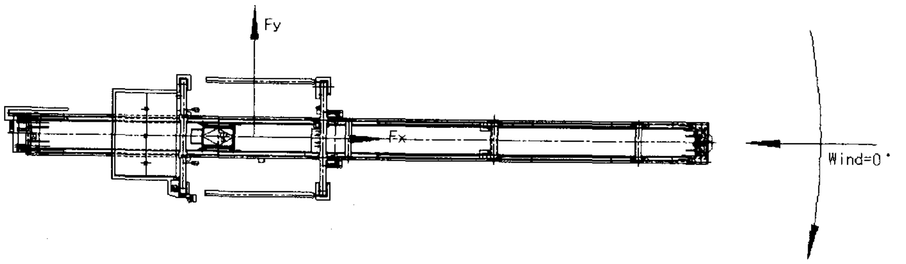


Fig. 8 Definition of incidence angle of wind load

3. Results and Discussions

Using Eq. (1) ~ (4), each directional drag and overturning moment coefficient was computed. 'B' and 'D' are the representational lengths of the container crane shown in Fig. 9. 'H' is the height of the container crane (64m) and 'q_H' is the standard wind pressure.

$$C_{Fx} = \overline{Fx}/(q_H BH) \qquad (1)$$

$$C_{Fy} = \overline{Fy}/(q_H DH) \qquad (2)$$

$$C_{Mx} = \overline{Mx}/(q_H DH^2) \qquad (3)$$

$$C_{Mx} = \overline{My}/(q_H BH^2) \qquad (4)$$

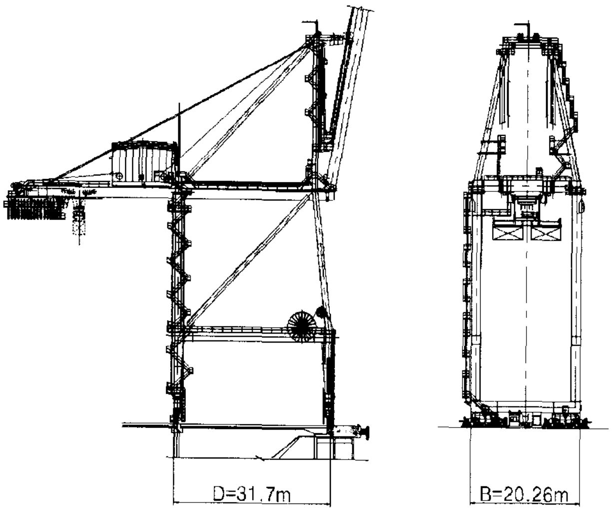


Fig. 9 Representational length of the container crane

In case of X-directional wind load coefficients, those at an incidence angle of 0°, which wind load apply to the front of container crane boom, had negative values, shown in Fig. 10. But those values became positive as an incidence angle of wind load was changed from 0° to 180°.

The maximum X-directional wind load coefficient values did not occur at 0° or 180° but at 20° or 170° because of the shielding effect between each member of container crane. In case of model 1, those at an incidence angle of 10° ~ 20° are 6.9% (case 1), 10.0% (case 2) and 8.6% (case 3) larger than at 0° at each case. And model 2, those are 9.8% (case 1), 7.0% (case 2) and 11.5% (case 3) larger.

Similar to X-directional wind load coefficients, the maximum Y-directional wind load coefficients values occurred at the vicinity of 70° or 10° but at 90°, which wind load apply to the container crane along the rail direction, shown in Fig. 11. In case of model 1, those at an incidence angle of 110° are 13.5% (case 1), 9.9% (case 2) and 7.2% (case 3) larger than at 90° at each case. And model 2, those are 6.1% (case 1), 8.3% (case 2) and 5.3% (case 3) larger.

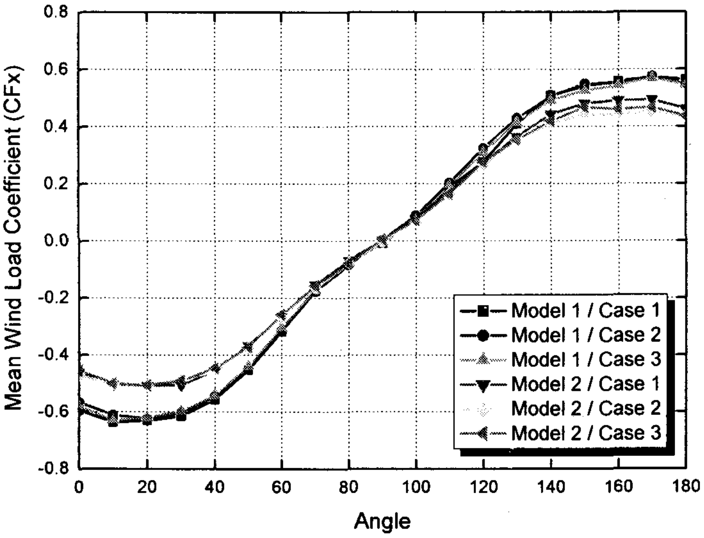


Fig. 10 Mean X-directional wind load coefficients according to incidence angle of wind load

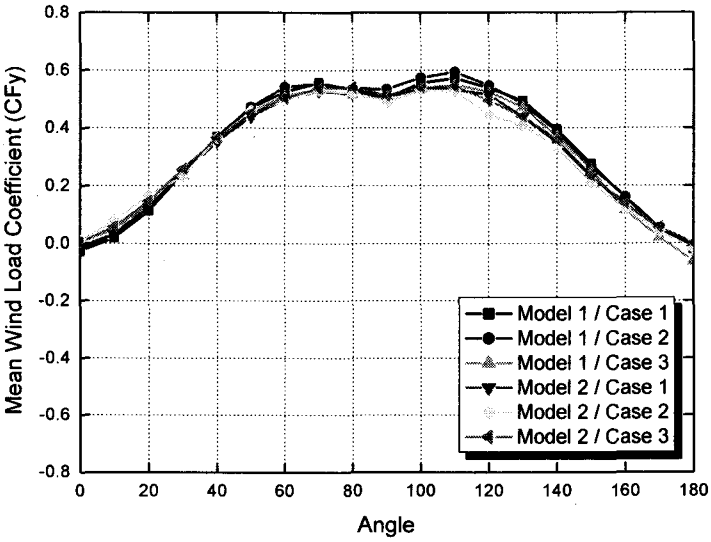


Fig. 11 Mean Y-directional wind load coefficients according to incidence angle of wind load

As X-directional wind load coefficients of model 1 were compared with those of model 2 at 0° or 180°, the values of model 1 were about 20% larger than model 2. Because model 2 had an articulated type boom, the wind load which applied on model 2 was smaller than that of model 1.

Fig. 12 shows X-directional overturning moment coefficients which represent the tendency to overturn a container crane due to Y-directional wind load. The maximum values of model 1 were -0.2942 (case 1), -0.2847 (case 2) and -0.2737 (case 3) and model 2 were -0.2401 (case 1), -0.2311 (case 2) and -0.2347 (case 3).

Deviations of Y-directional wind load coefficients according to the boom shape were not so large. But X-directional overturning moment coefficients of model 1 were 16 % ~ 31% larger than those of model 2 at angles from 110° ~ 160° because the overturning moment coefficient is in inverse proportion to the square of the height of the container crane, 'H'.

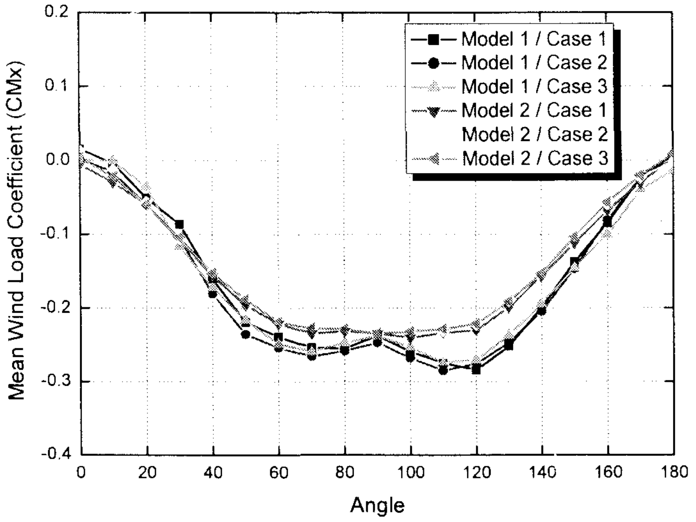


Fig. 12 Mean X-directional overturning moment coefficients according to incidence angle of wind load

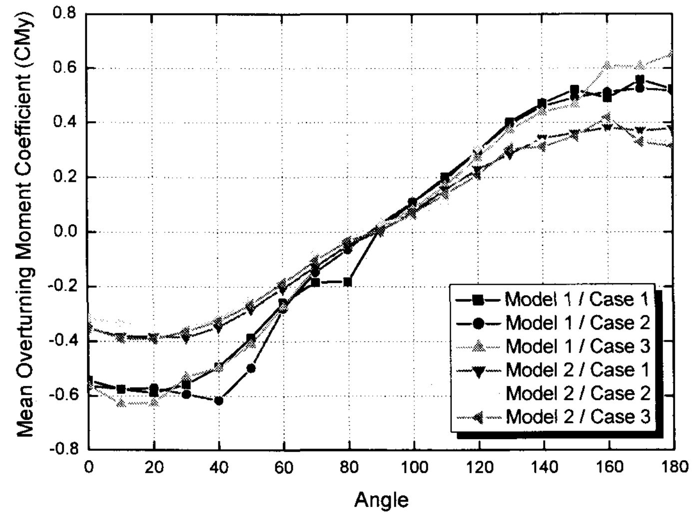


Fig. 13 Mean Y-directional overturning moment coefficients according to incidence angle of wind load

Fig. 13 shows Y-directional overturning moment coefficients. Similar to X-direction, Y-directional overturning moment coefficients of model 1 were 30% ~ 40% larger than those of model 2 at 0° and 180°.

The maximum Y-directional overturning moment coefficient values for each case were twice as large as those for the X-direction. To compare with the maximum values according to the boom shape, in case of model 1, the maximum values were -0.5886 (case 1), -0.6061 (case 2) and 0.6508 (case 3) and model 2 were -0.3828 (case 1), -0.3508 (case 2) and -0.3915 (case 3).

The distribution of X and Y directional overturning moment coefficients with respect to the change of the machinery house location were almost the same, like a distribution of drag coefficient at any angle. However in the case of Y-direction, results with comparatively large variations occurred at some angles. This was due to an error which occurred in the measuring process during the wind tunnel test.

The distribution of drag coefficient according to the wind load direction was compared with that of overturning moment coefficient, and they were found to have almost same distribution at any angle. The incidence angle of wind load at which the maximum value of each coefficient occurred was not at 0° or 90° with respect to the container crane, but at 20° or 110°.

Generally, as the wind load is computed for the X (0°) and Y (90°) directions at the container crane design stage, we need to apply compensational factors to the container crane design in order to consider an inclined wind load effect.

4. Conclusions

In this paper, by analyzing the effect of wind load on the stability of a 50-ton container crane with conventional type and articulated type boom using a wind tunnel test, we furnished each directional drag and overturning moment coefficient according to incidence angle, and also the estimation method for uplift forces at each supporting point of the crane under wind load. Designers could use these data for improving the wind resistance of container cranes.

Following from this, if we perform finite element analysis for each case for an improved type of container crane, using the wind load coefficients furnished in this study and comparing these results with wind tunnel test results, the stowing devices and stowed configuration of future container cranes may be designed more precisely because the uplift forces affecting them can be more accurately calculated.

Acknowledgement

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References

(1)Han G. J., Lee H., Shim J. J., Han D. S., Ahn C. W. and Jeon Y. H. (2004) : Study on the Wedge Angle of Wedge Type Rail Clamp for Container Crane, *J. of KSPE* 21(9), 119-126.

(2)Hanjin Heavy Industries & Construction Co. Ltd. (2000) : Structural & Mechanical Calculation for 50-Ton Container Crane for Pusan Port.

(3)Jang H. S., Kim Y. S. and Hwang K. S. (1997) : Introduction of Wind Tunnel Laboratory in Hyundai Institute of Construction Technology, *J. of WEIK* 1(1), 58-65.

(4)Kang S. H., Lee D. H., Cho K. J., Choi S. H. and Huh J. (1988) : Experimental Studies on the Estimation of Wind-Load of a Container Crane and Its Development, *J. of KSME* 12(4), 892-899.

(5)Lee S. W., Shim J. J., Han D. S., Park J. S., Han G. J., Lee K. S. and Kim T.H. (2005) : The Effect of Wind Load on the Stability of a Container Crane, *J. of KSPE* 22(2), 148-155.

(6)Ministry of Construction & Transportation of the Korean Government (2000) : Design Criteria of a Road Bridge.

(7)Ministry of Construction & Transportation of the Korean Government (2000) : Load Criteria of Building Structures.